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TROPICAL PROPAGATION RESEARCH

L. G. Sturgill

Atlantic Research Corporation
Alexandria, Virginia

31 July 1967

JANSKY & BAILEY ENGINEERING DEPARTMENT

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Semiannual Report Number 9

1 Jan 1967 - 30 June 1967

Prepared for

U.S. ARMY ELECTRONICS COMMAND

Fort Monmouth, New Jersey

Signal Corps Contract

DA 36-039 SC 90889

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY

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ARPA ORDER 371

ATLANTIC RESEARCH

A DIVISION OF THE SUSQUEHANNA CORPORATION

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Approved by

Frank T. Mitchell, Jr.
Division Director

L. G. Sturgill
Project Director

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ACKNOWLEDGMENT

This extensive radio propagation study program in Thailand has been possible only through the invaluable support of several organizations there. Jansky & Bailey particularly wishes to express its gratitude for the cooperation and assistance received from the Joint Thai - U. S. Military Research and Development Center in conducting the field measurements described in this report.

ABSTRACT

This is the ninth semiannual report of a research project to study radio propagation in tropical areas with heavy vegetation. The experimental results reported here are from the first series of tests conducted near the towns of Songkhla and Satun in southern Thailand (Area II). The test area, which receives about 90 inches of rainfall annually, is covered with extremely thick jungle. Graphs are presented of basic transmission loss as a function of distance out to 1.4 miles for frequencies of 25, 50, 100 and 250 Mc/s using different transmitting antenna heights, polarizations and transmission paths. The receiving antenna height is fixed at 6 feet. Certain of these tests are compared with identical ones made previously in the jungles near Pak Chong, Thailand, (Area I) where the vegetation is significantly lower and less dense. The climate in the test area is also described and compared with the climate at the Area I site.

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1. INTRODUCTION

Semiannual Report Number 9 covers the research and analysis work of the Tropical Propagation Research Project from January through June 1967. This project is conducted in Thailand by the Jansky & Bailey Engineering Department of Atlantic Research Corporation. The work is sponsored by the Advanced Research Projects Agency of the Department of Defense as a part of SEACORE and is under the technical and contractual direction of the U. S. Army Electronics Command, Fort Monmouth, New Jersey.

The purpose of this research program is to determine the nature and magnitude of the influences on short-range tactical communication due to the environment. This knowledge will eventually enable one to predict the performance of a given communication system within any environment and will help in the design of new communication equipment.

In the first phase of this program, an extended series of tests through the 0.1-10,000-Mc/s frequency range was conducted in a medium heavy jungle near Pak Chong, Thailand (Area I). This type of vegetation, referred to as "wet-dry" jungle, is commonly found in Southeast Asia. The second major phase of the test program, now in progress, was initiated to study radio propagation in significantly heavier vegetation. These present tests are being conducted in a "rain forest" type of jungle between the towns of Songkhla and Satun in the southern peninsula of Thailand (Area II).

Although the Area II tests are generally not as extensive as those conducted at Area I, the results of data analysis from that area indicated that certain kinds of propagation should be investigated more extensively than others. In particular, short-range propagation is being more exhaustively studied at the Area II site since it has been found that most environmental effects occur relatively near the antennas.

Semiannual Report Number 9 is primarily devoted to a presentation of the very large amount of propagation data that has been collected within one and a half miles of the transmitting antennas during the first part of the Area II measurement program. This report does not contain a description of the test area or of the test procedures and instrumentation, since this information was given in the previous semiannual report (number 8).

Section 2 of this report contains 112 sets of curves which cover all the primary tests in the short-range measurements. The curves represent values of basic transmission loss which are derived from readings of field strength taken at different distances from the transmitting antennas. The equation used to calculate basic transmission loss (L_b) from field strength readings is the same one used in previous semiannual reports. It is expressed as

$$L_b = 36.57 + 20 \log f + 20 \log E_1 - 20 \log E_{meas}$$

where

L_b = basic transmission loss in dB

f = frequency in megacycles per second

E_1 = unattenuated field strength in μv/m expected from the transmitting system at 1 mile

E_{meas} = any measured value of field strength produced as a result of radiation from the transmitting system used to determine E_1 above

Each set of path loss curves carries a concise, systematic notation identifying the parameters of that particular test. The notation is

$$L_b = F_T(f, H_t, P, d, H_r)$$

This format indicates that the basic transmission loss "L_b" shown by the curves is a function "F" of six variables. The first is the subscript "$_T$" following the "F" and indicating the test trail or trails on which data was gathered. The other five variables within the parentheses are explained below.

f = frequency in megacycles per second

H_t = transmitting antenna height in feet

P = transmitted polarization denoted as "H" or "V"

d = transmission distance in feet or miles

H_r = receiving antenna height in feet

For example, in Figure 2.2 the identifying equation reads

$$L_b = F_X(25, \text{Gnd.}, V, d, 6.0)$$

This means it is a graph of path loss measured on trail "X" at a frequency of 25 Mc/s, using a transmitting antenna at ground level, vertical polarization, and a receiving antenna height of 6 feet. The "d" indicating distance does not have a value because it is a variable rather than a parameter in this graph.

The presentation of the complete set of graphs for all combinations of test parameters in the short-range measurements constitutes the main portion of Section 2.

Section 3 presents the results of certain identical tests which were made at the Area I and Area II test sites. Data from the two areas is compared by superimposing the two equivalent sets of curves on one figure.

In Section 4 the climatological measurements made at Area II to date are presented and discussed. Since the essential difference in the two Area I and Area II test sites is the thickness and height of their vegetative cover, which in turn is primarily a product of their different climates, a comparison of the main climatological characteristics of the two sites is also included.

Figure 1.1 shows a map of Thailand giving the locations of test sites, Areas I and II.

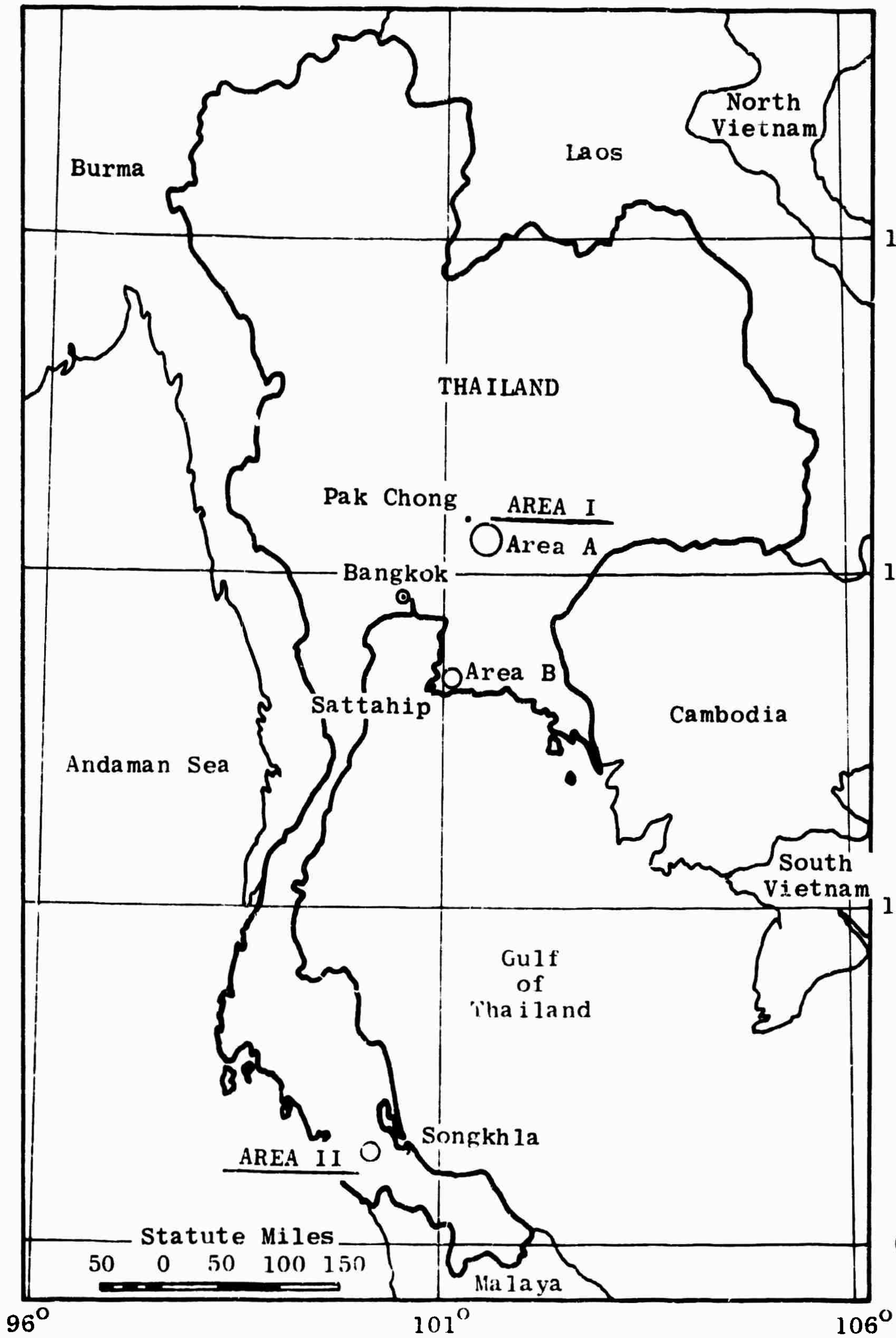

Figure 1.1 Locations of Thailand Test Areas

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2. PRIMARY WALKING DATA

The first series of measurements at the Area II test area was undertaken to obtain a detailed record of short-range path loss in an area covered with heavy jungle. These measurements were made along four trails which were cut through the vegetation for about one and a half miles. Because the receiving equipment was hand carried along these trails, the measurements are termed "walking measurements" and the data from them is called "walking data."

The four test trails extend radially from a bench mark located near the transmitting antenna pads. On each of the four trails, named "W," "X," "Y," and "Z," are 52 points where measurements were taken. These measurement points are already spaced near the transmitting antenna, but are further apart at greater transmission distances. Their spacing is listed in Table 2.1.

Table 2.1

SPACING BETWEEN MEASUREMENT POINTS

Spacing (feet)	Distance from Bench Mark (feet)
50	0 - 1000
100	1000 - 2500
200	2500 - 4900
500	4900 - 7400

A single set of primary walking data consists of the maximum and minimum field strengths in the near vicinity of each measurement point along a particular radial. This data was taken over the four radials with horizontally and vertically polarized signals which were transmitted at 25, 50, 100 and 250 Mc/s. The transmitting antennas were located at ground level and at 6-, 13-, 40-, 80- and 120-foot elevations.

Altogether, 112 different combinations of these test parameters were used. This total represents slightly more than half of the possible total of 192 different tests (six antenna heights times four frequencies times four trails times two polarizations). It was not possible to transmit each frequency-polarization combination from every antenna height, and in many cases it was adequate to conduct certain tests on just two or three rather than all four radial trails.

To calculate the transmission distance associated with each measurement, the particular point, radial and transmitting antenna height must be taken into account. As shown in Figure 2.1, the ground level transmissions were made 238 feet from the bench mark; 6- and 13-foot-high antennas were placed at points 50 feet out on each radial; and 40-, 80- and 120-foot-high antennas were positioned on an adjustable, permanently installed mast 23 feet from the bench mark. At each measurement point there is a number which, when multiplied by 100, gives the distance of the point from the bench mark. The computer routine which calculates basic transmission loss from field strengths uses this information to determine the path length between each measurement point and the transmitting antenna being used

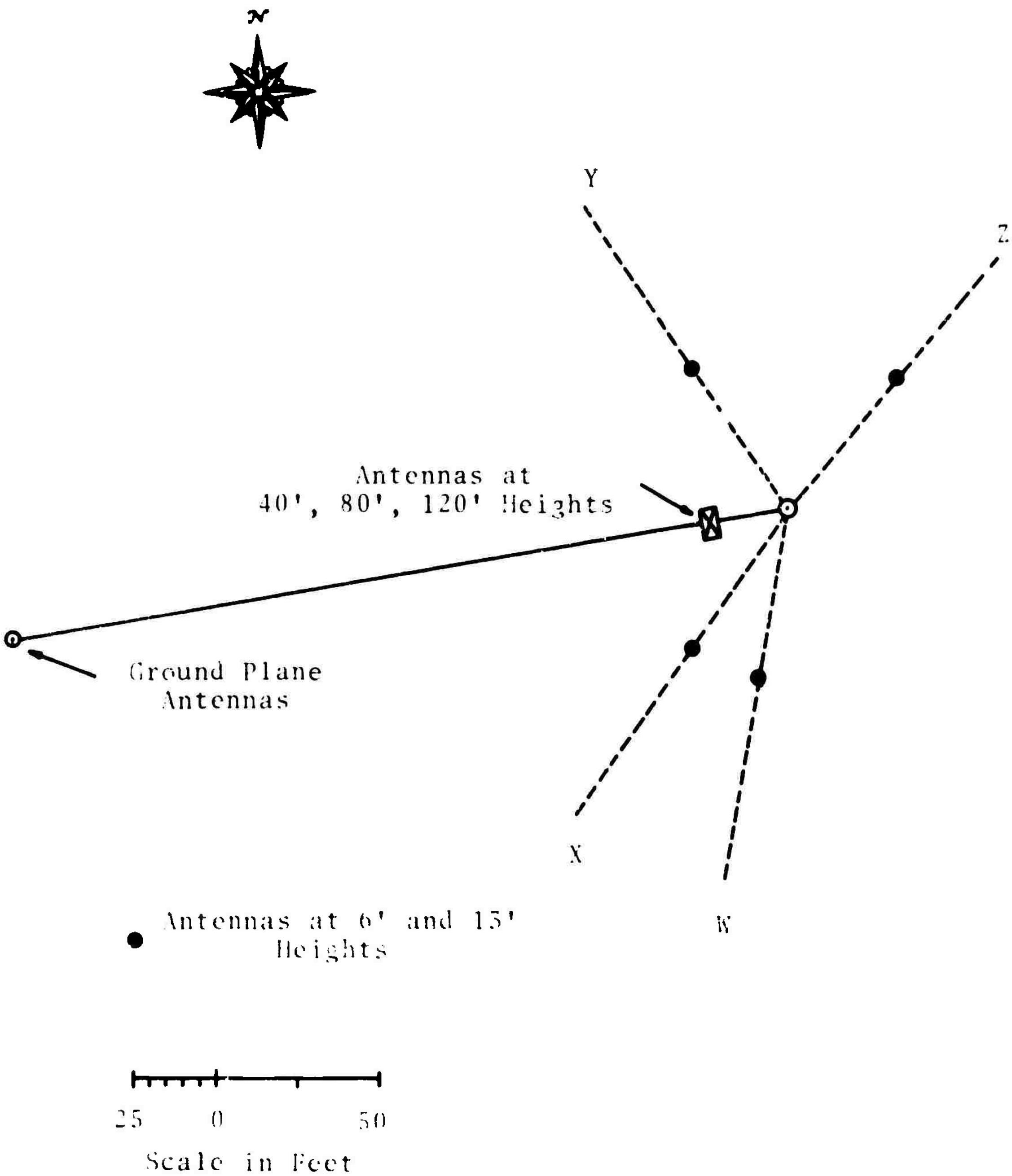

Figure 2.1 Transmitting Location and Trail Layout for Walking Measurements

Actual line-of-sight distances are tabulated in Semiannual Report Number 8.

All primary data consisted of measurements made with hand carried receiving antennas held 6 feet off the ground. For the loop receiving antennas used at 25 Mc/s, this distance is measured from ground to the center of the loop. For the dipoles used at 50, 100 and 250 Mc/s, the distance is from the midpoint of the dipole, whether it is held vertically or horizontally. Receiving and transmitting antennas were oriented for maximum free-space gain. In addition, special measurements were made at points 2, 10, 25 49 and 74 (respectively 200, 1000, 2500, 4900 and 7400 feet from the bench mark) to determine the effects of changing the height, polarization and orientation of the receiving antennas. The results of these tests, called "supplementary tests," will be contained in a later report.

In the primary tests, the receiving antenna is moved back and forth along the trail about 10 feet from each measurement point to get a maximum and minimum reading of the rapid variations in field strength. Where it is impossible to get a definite maximum and minimum, as many as seven random readings are taken in the general area of the measurement point. All this data is later put on punched cards and converted by computer to values of basic path loss. The computer picks the highest and lowest values of field strength associated with each point and computes from them the minimum and maximum path loss, respectively. A description and explanation of the procedures for recording, transferring, and reducing the data to basic path loss are contained in Semiannual Report Number 8.

The calculated values of basic path loss (denoted by "L_b") are plotted against distance in Figures 2.2-2.113. To allow a visual correlation of path loss variations with terrain variations, a linear distance scale has been used, and on the bottom of each graph is the terrain profile of the particular trail along which the data was taken. Because of the offset from the bench mark of the ground plane transmitting antennas, the terrain profiles for the six figures with this test parameter may differ slightly from the actual profile along the propagation path for the first 1000 feet.

The two path loss curves above the terrain profile represent the maximum and minimum amount of path loss at each point. The distance between the curves can be regarded as the amount of variability in path loss over 10- to 20-foot distances in the jungle. In instances where the measured field strength was 1 to 6 dB above the noise level of the instrument, the reading was corrected for noise. Dotted portions of the path loss curves indicate where this correction was made, such as at 4000 feet on Figure 2.2. When the signal level dropped to the noise level, the data was not used. The lower curve in Figure 2.2 is plotted only to about 1800 feet for this reason.

The test parameters of each of the figures are given by the identifying code explained in Section 1. The combination of a letter and number that follow the identifying code on each figure is the reference number of the data set.

The figures are arranged in order of increasing frequency. For each frequency, tests using vertical polarization are placed before those using horiz`ntal polarization. Each polarizatiun group is arranged by increasing antenna height. Thus, graphs of similar tests perfor:ed ɔng different trails are grouped together. This arrangement affords a means of comparing how different terrain profiles affect the path loss curves. To simplify locating particular test parameters within this large group of curves, Table 2.2 lists the figure numbers associated with each combination of parameters.

Table 2.2

LIST OF FIGURE NUMBERS FOR TEST PARAMETERS

Freq. (Mc/s)	Pol.	Transmitting Antenna Height (feet) 0	6	13	40	80	120
25	V	2.2 -2.4		2.5 -2.8	2.9 -2.11	2.12 -2.13	2.14 -2.16
	H			2.17 -2.20	2.21 -2.23	2.24 -2.27	2.28 -2.30
50	V	2.31-2.33		2.34 -2.37	2.38 -2.40	2.41 -2.44	2.45 -2.47
	H			2.48 -2.51	2.52 -2.54	2.55 -2.58	2.59 -2.61
100	V		2.62-2.63	2.64 -2.67	2.68 -2.71	2.72 -2.74	2.75 -2.77
	H		2.78-2.79	2.80 -2.83	2.84 -2.87	2.88 -2.90	2.91 -2.93
250	V			2.94 -2.97	2.98 -2.99	2.100-2.101	2.102-2.103
	H			2.104-2.107	2.108-2.109	2.110-2.111	2.112-2.113

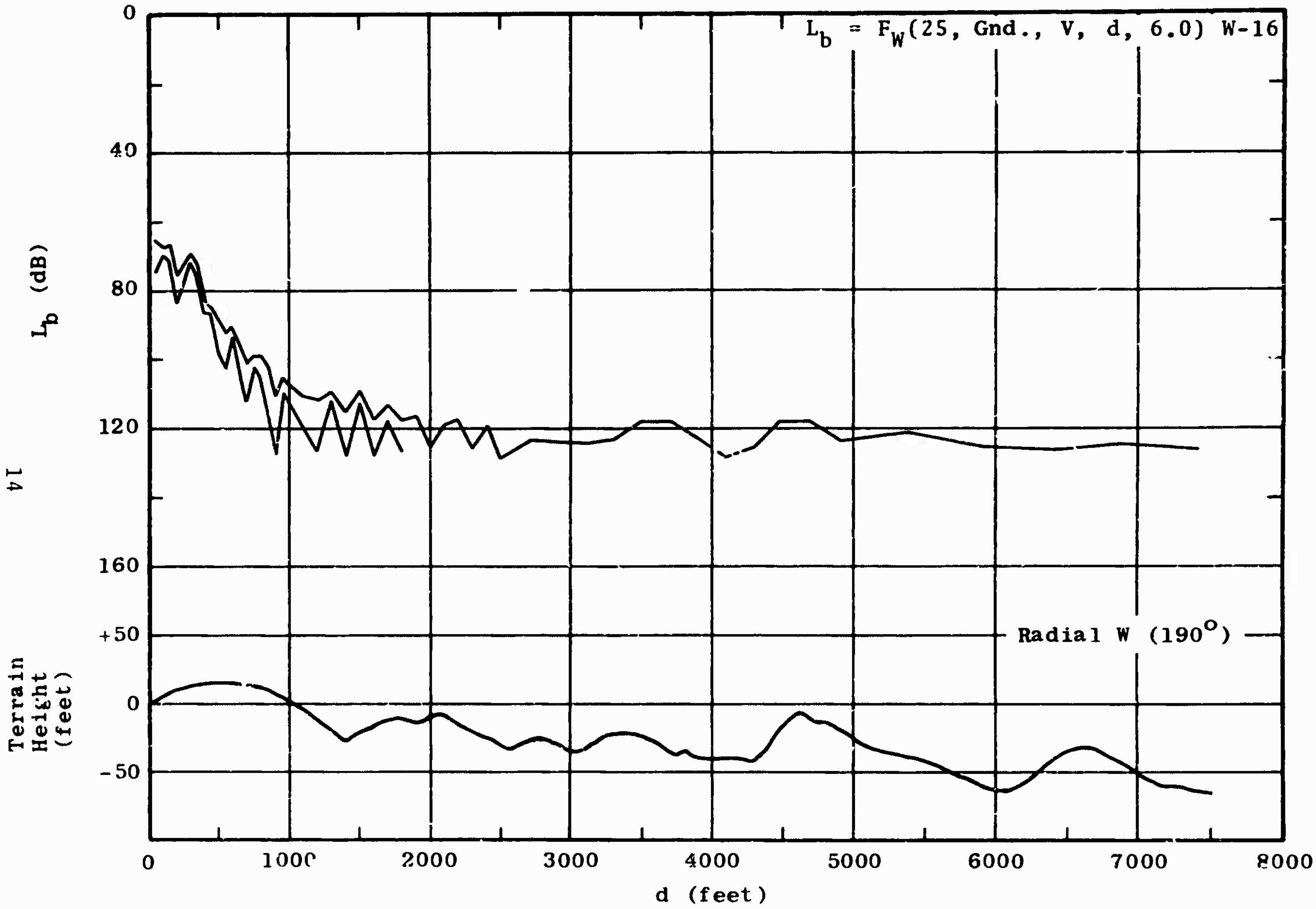

Figure 2.2 Maximum and Minimum Basic Transmission Loss as a Function of Distance

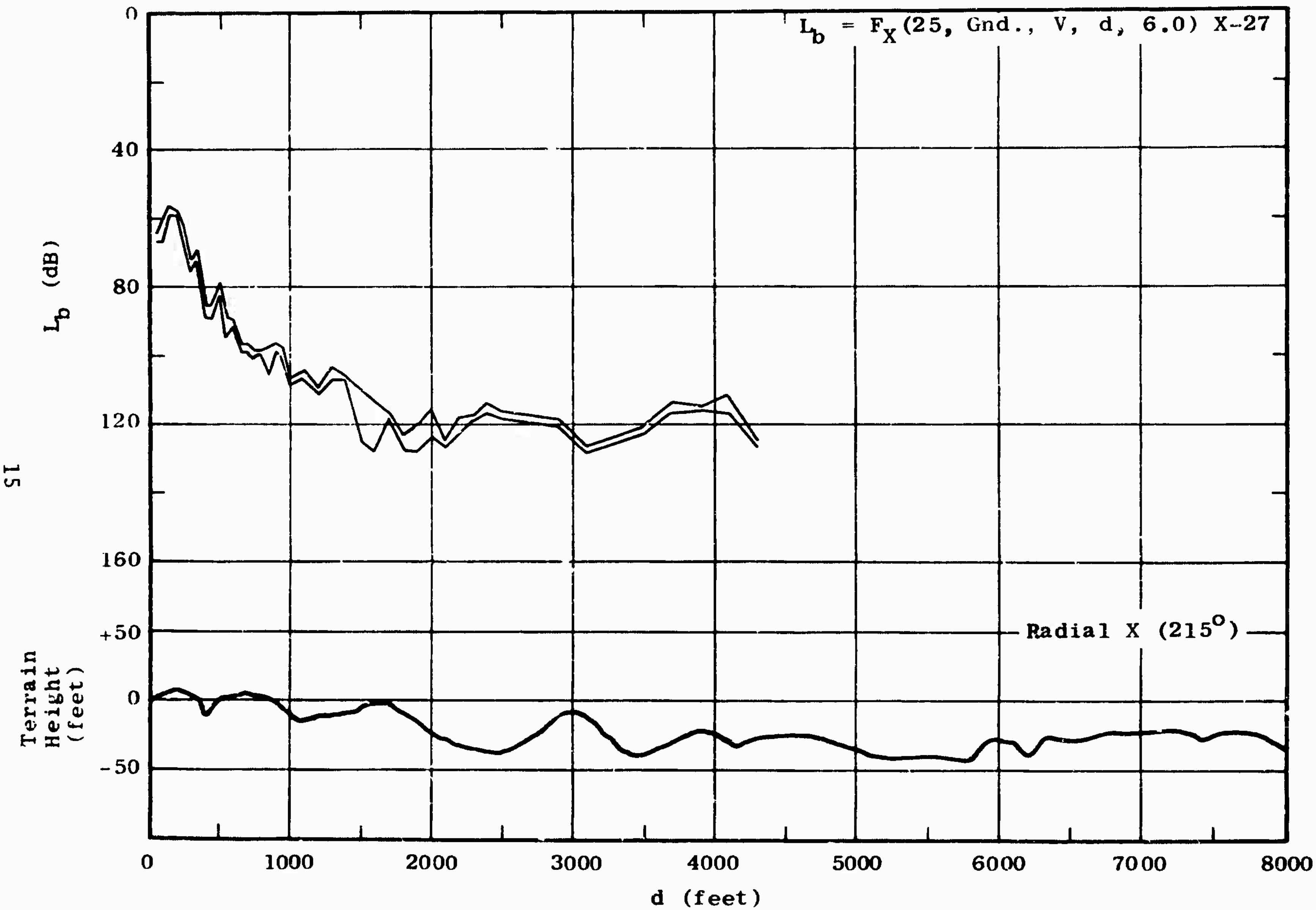

Figure 2.3 Maximum and Minimum Basic Transmission Loss as a Function of Distance

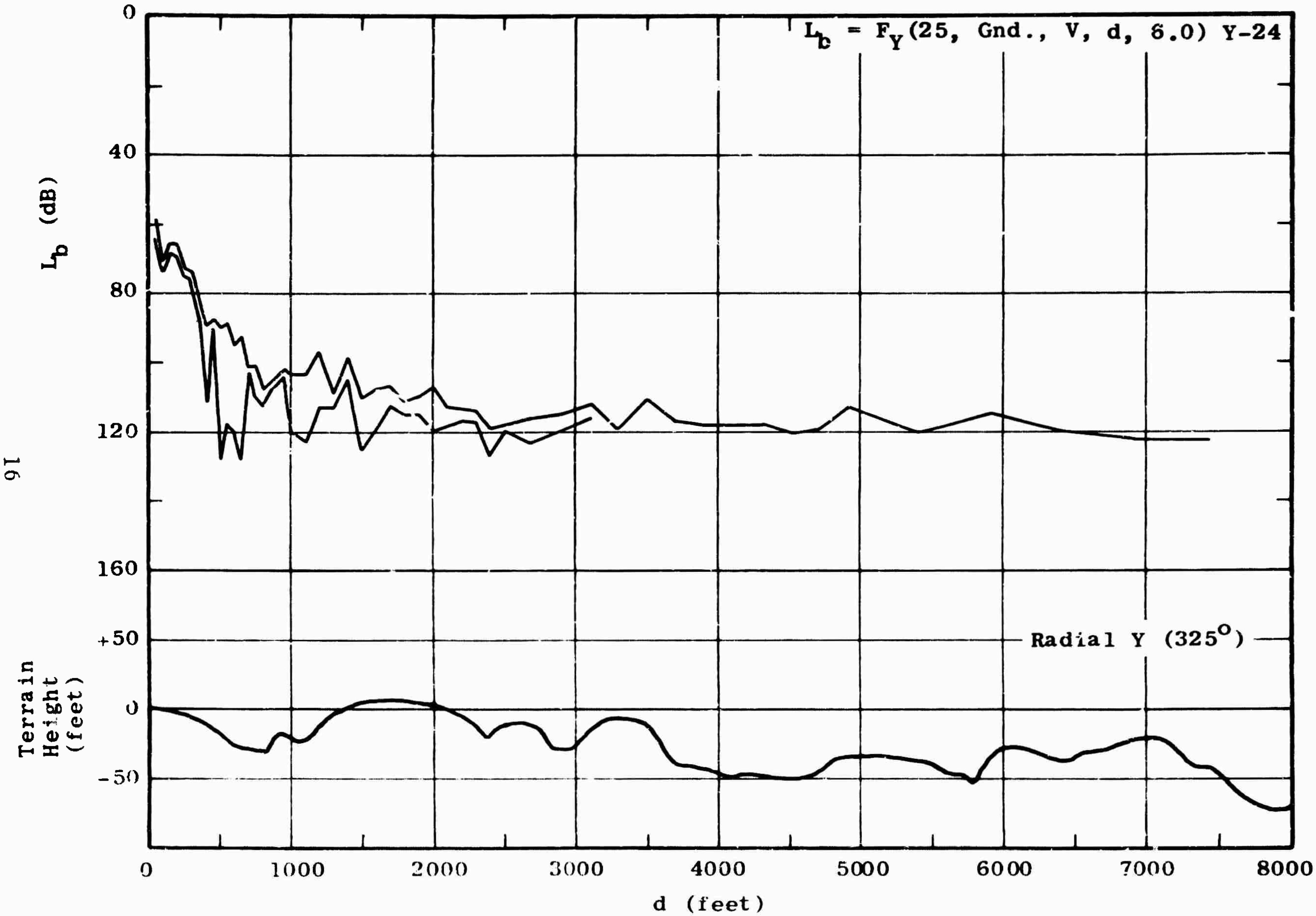

Figure 2.4 Maximum and Minimum Basic Transmission Loss as a Function of Distance

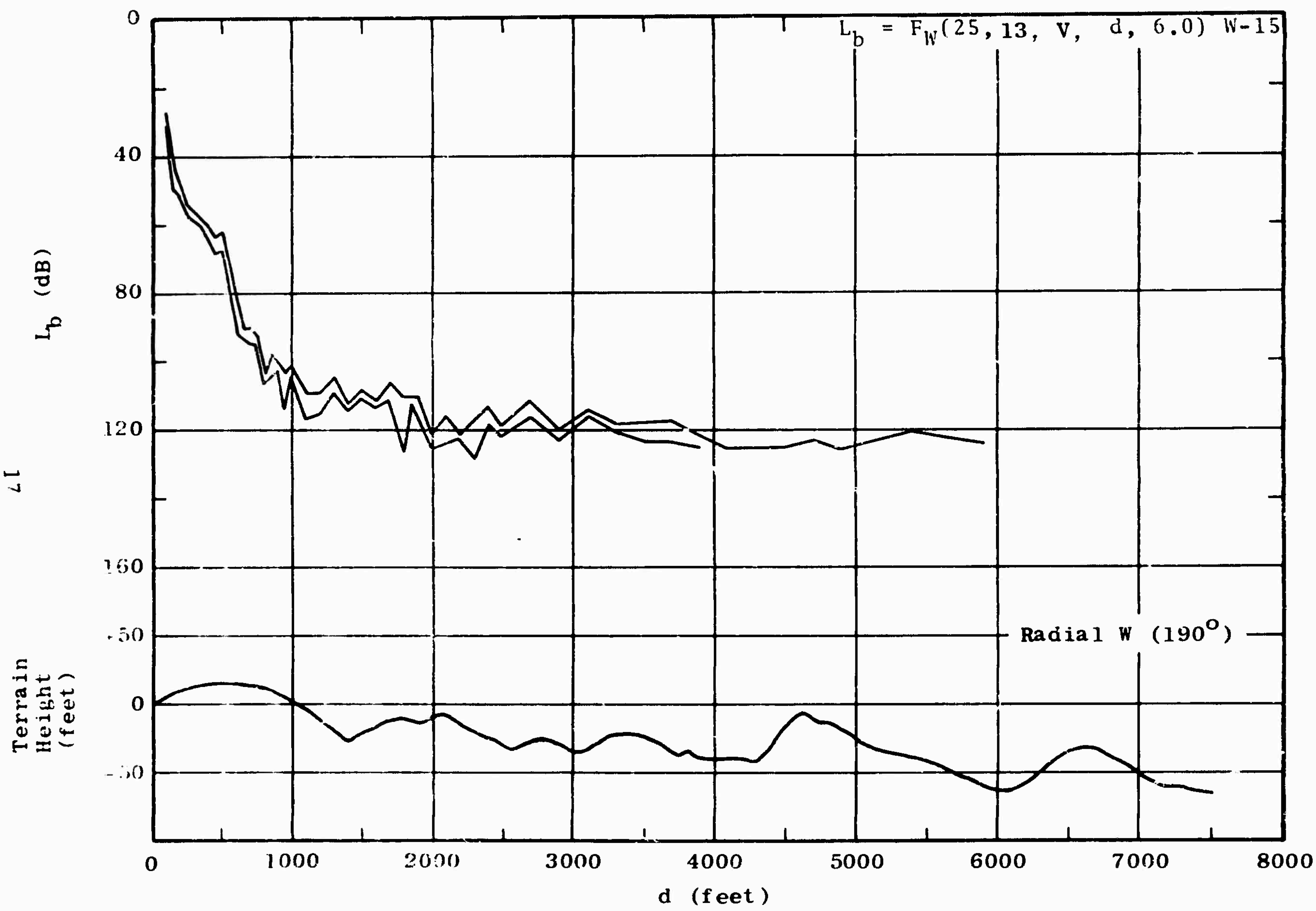

Figure 2.5 Maximum and Minimum Basic Transmission Loss as a Function of Distance

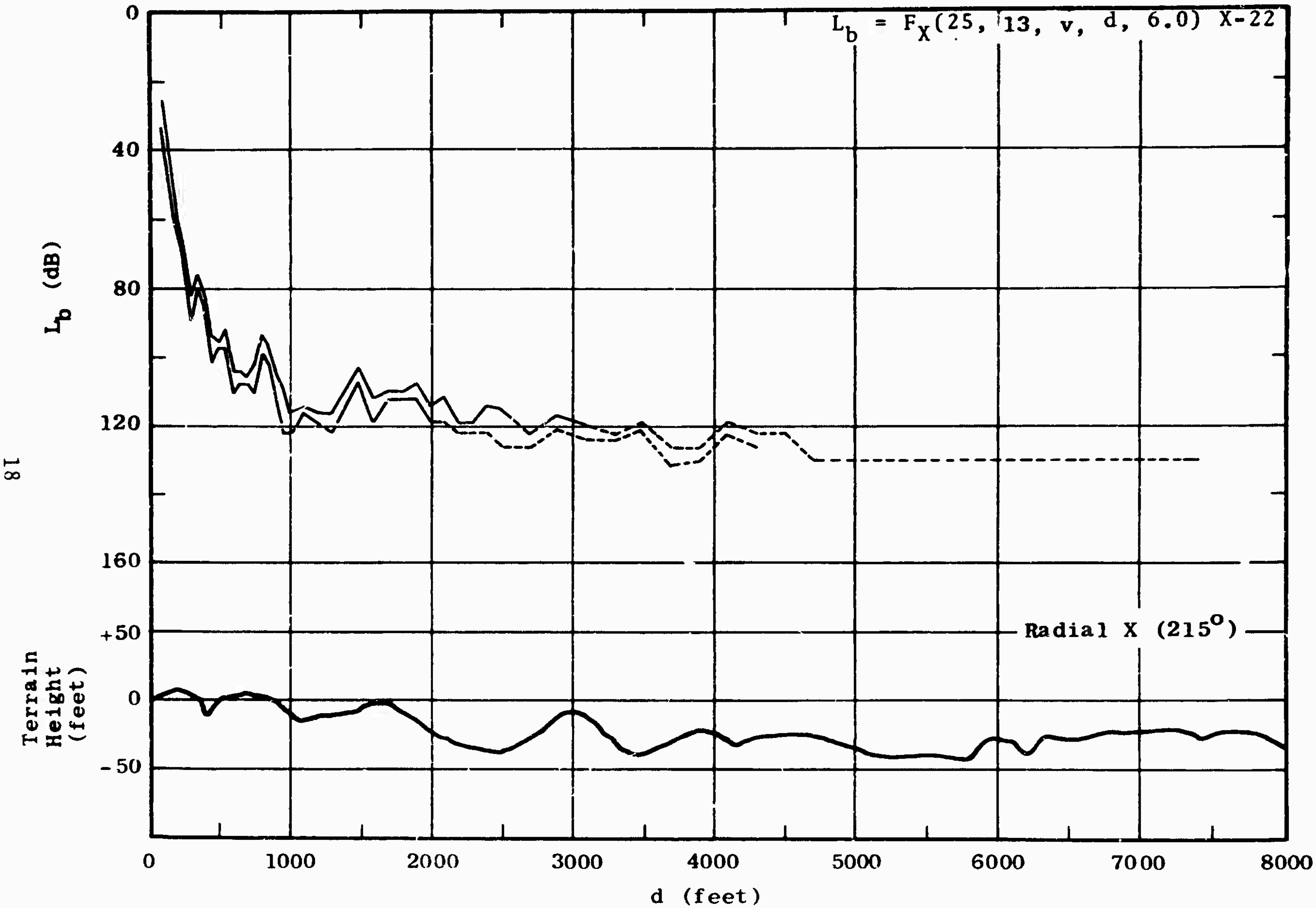

Figure 2.6 Maximum and Minimum Basic Transmission Loss as a Function of Distance

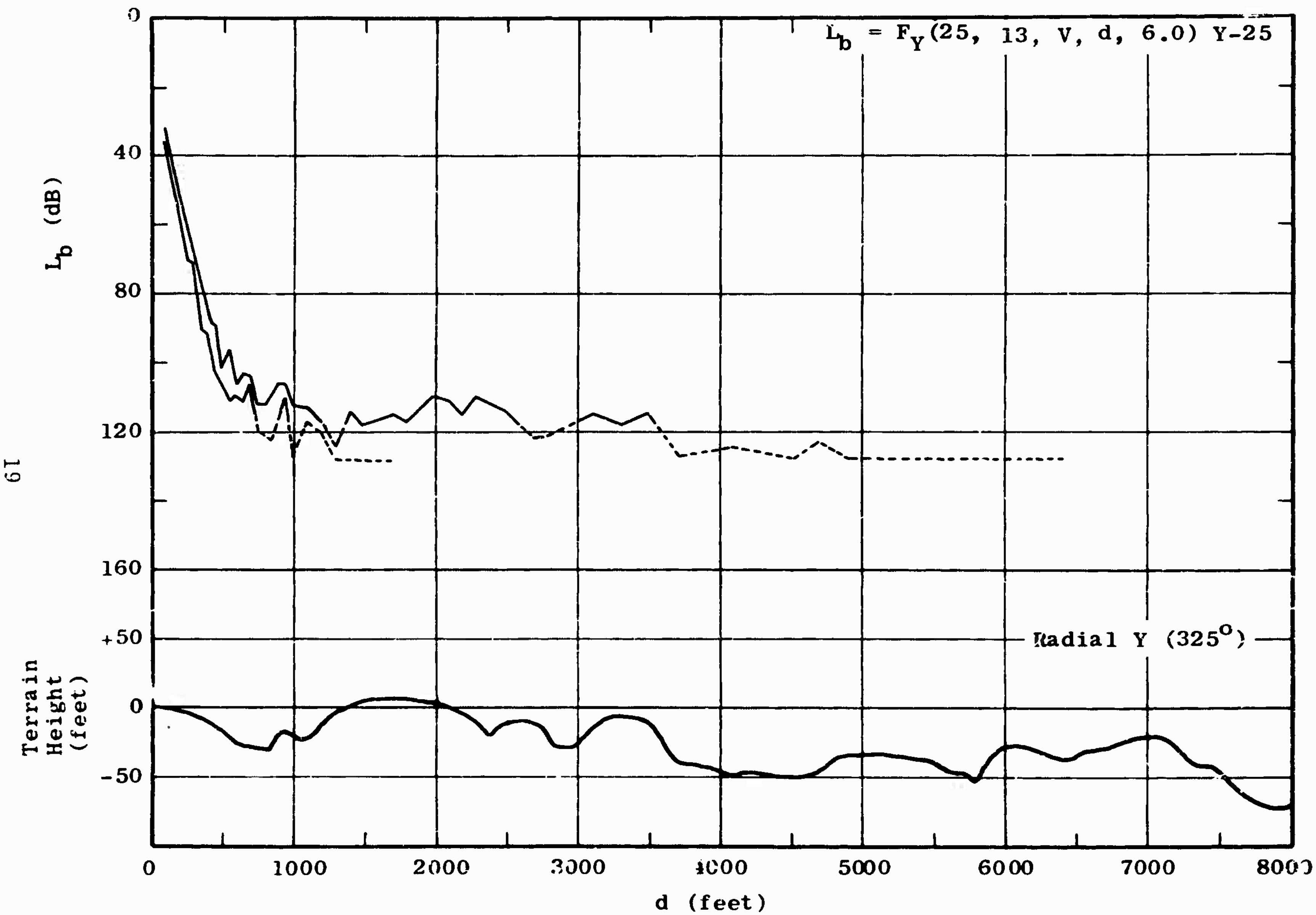

Figure 2.7 Maximum and Minimum Basic Transmission Loss as a Function Of Distance

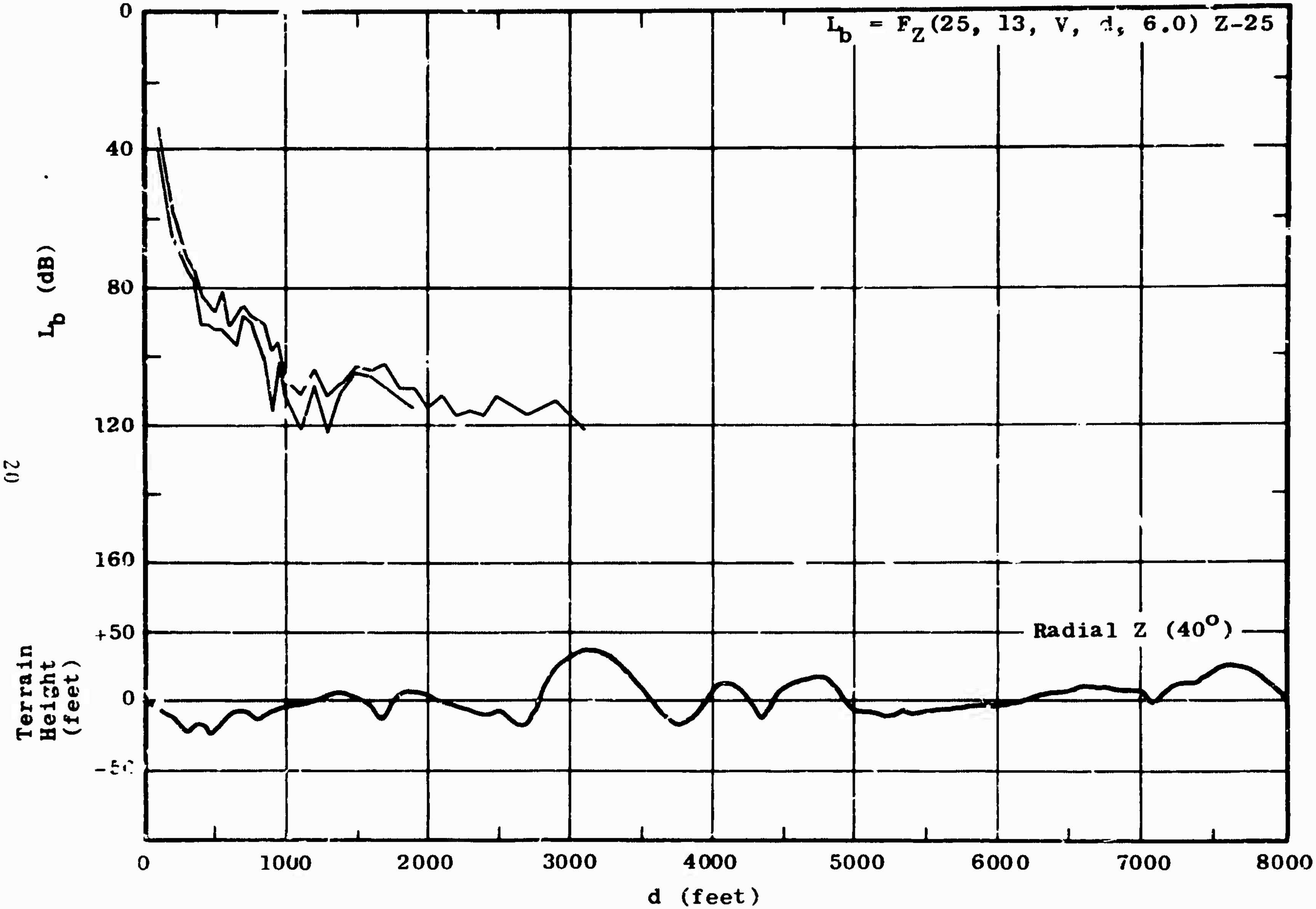

Figure 2.8 Maximum and Minimum Basic Transmission Loss as a Function of Distance

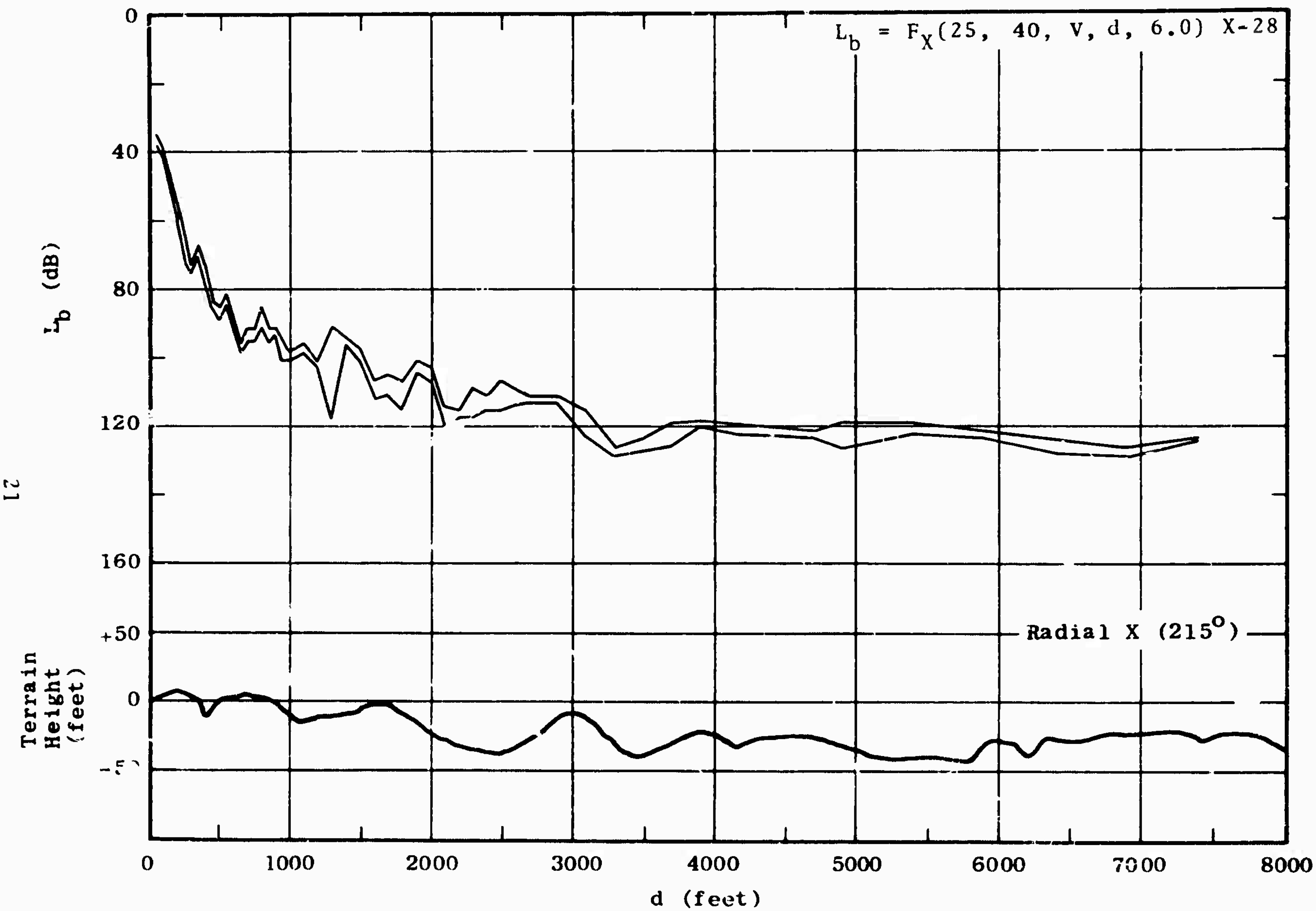

Figure 2.9 Maximum and Minimum Basic Transmission Loss as a Function of Distance

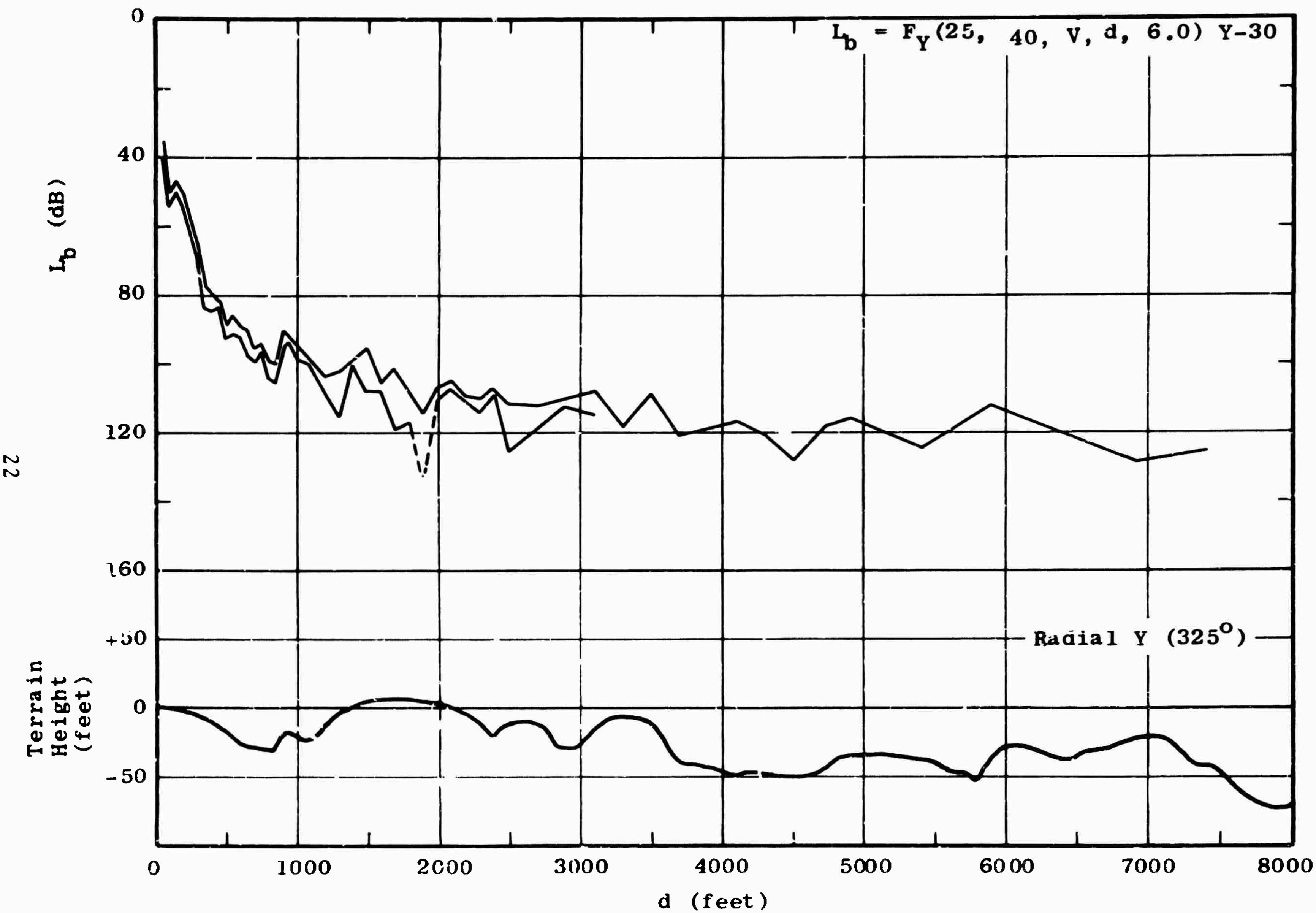

Figure 2.10 Maximum and Minimum Basic Transmission Loss as a Function of Distance

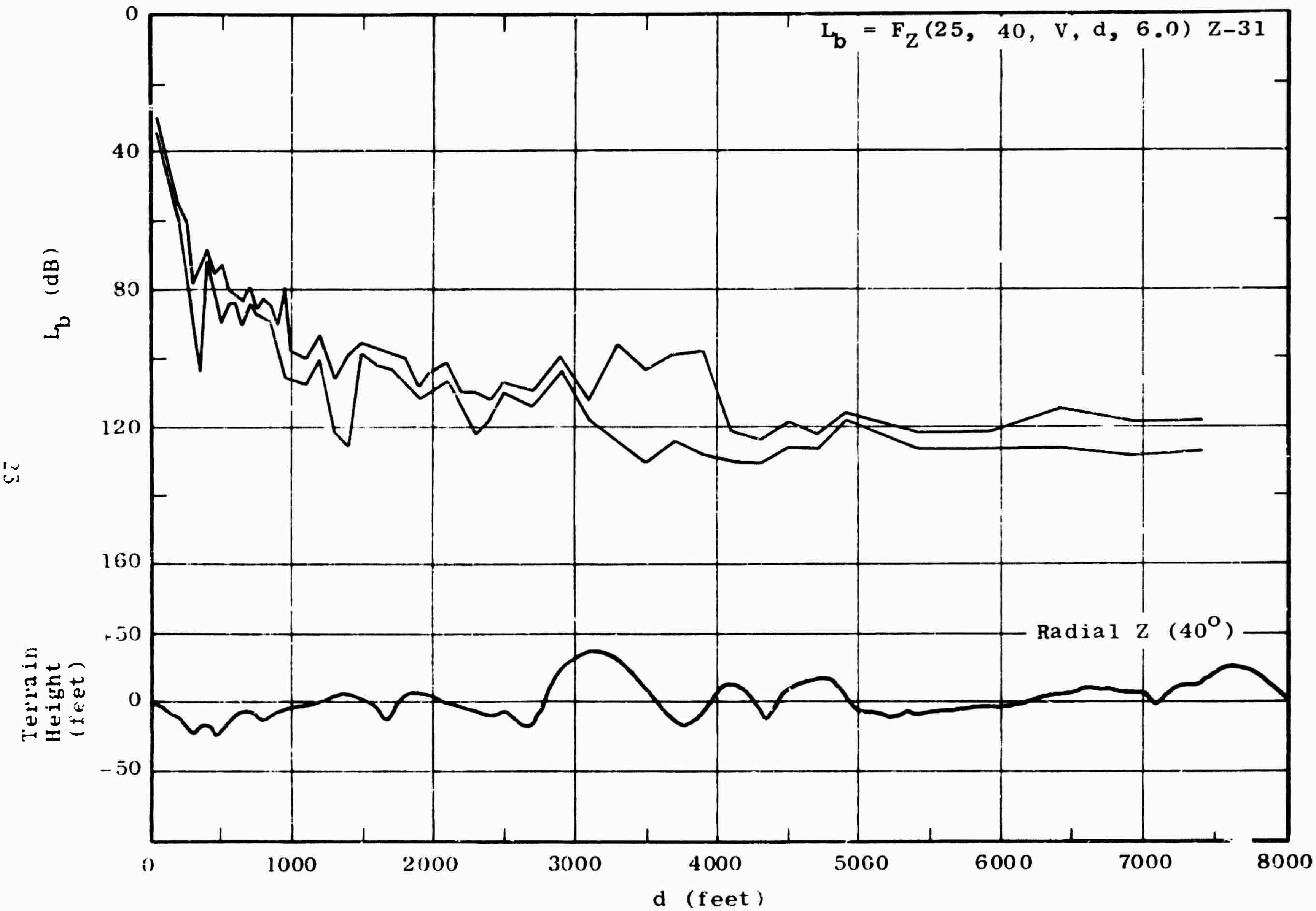

Figure 2.11 Maximum and Minimum Basic Tra .mission Loss as a Function of Distance

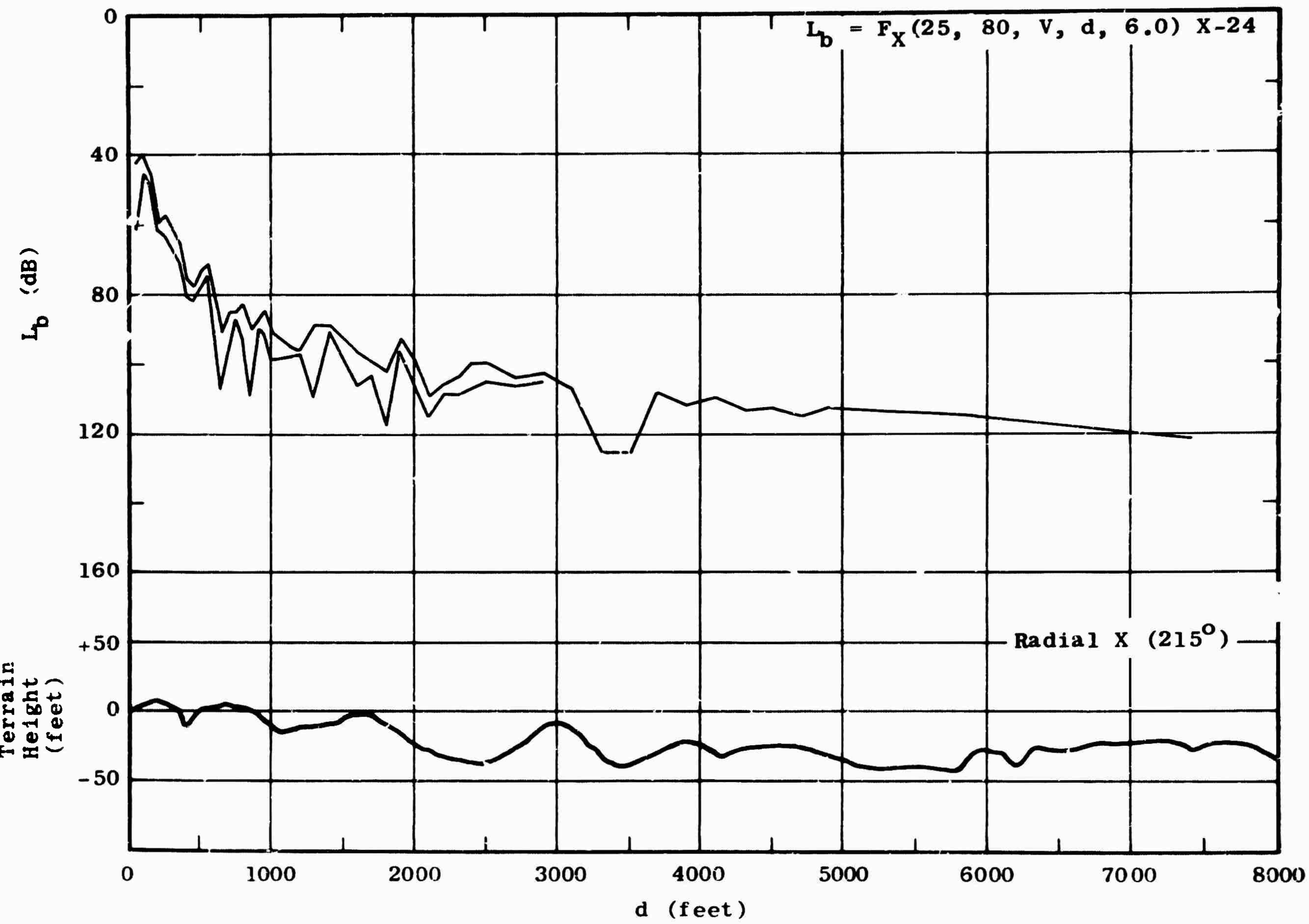

Figure 2.12 Maximum and Minimum Basic Transmission Loss as a Function of Distance

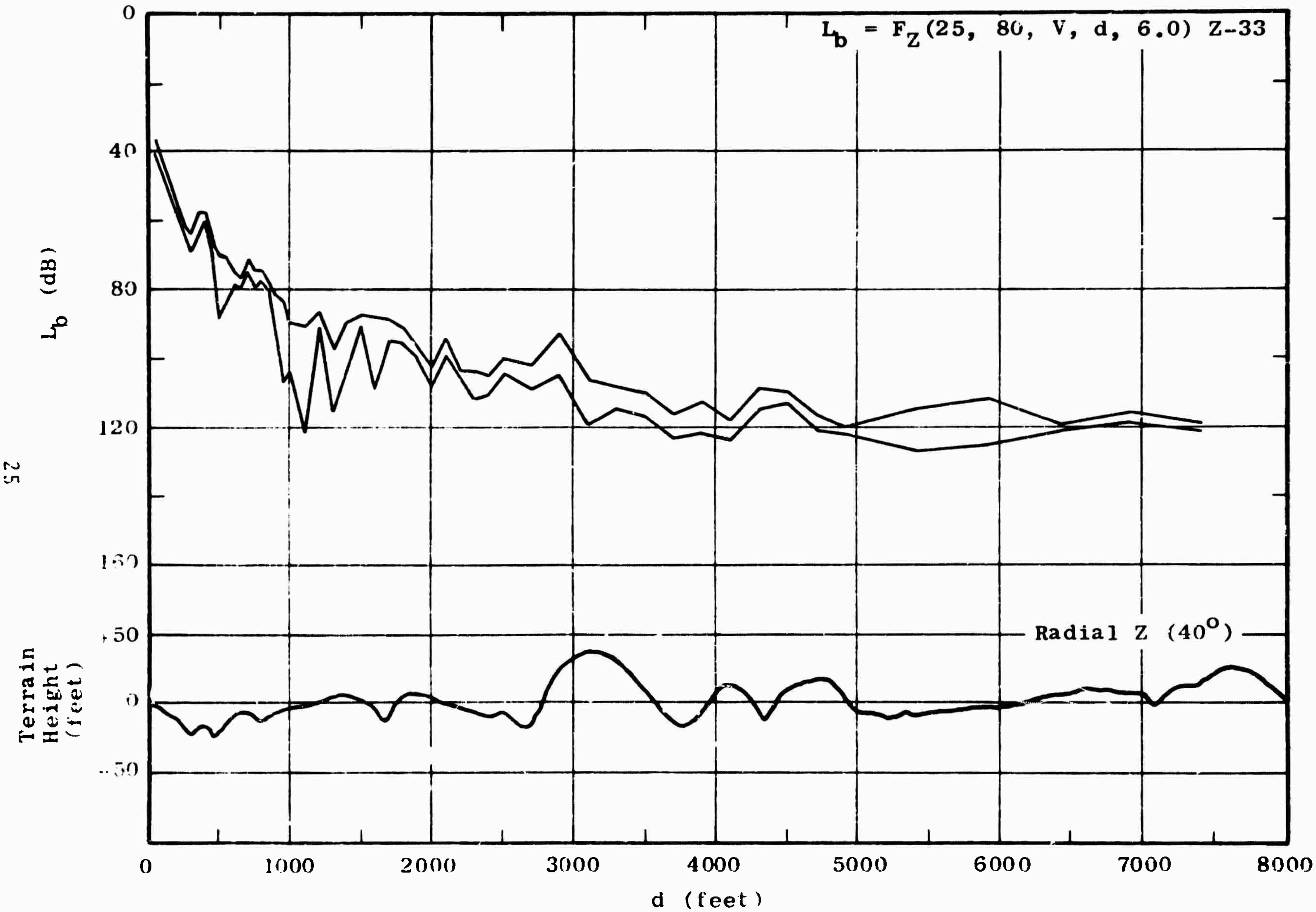

Figure 2.13 Maximum and Minimum Basic Transmission Loss as a Function of Distance

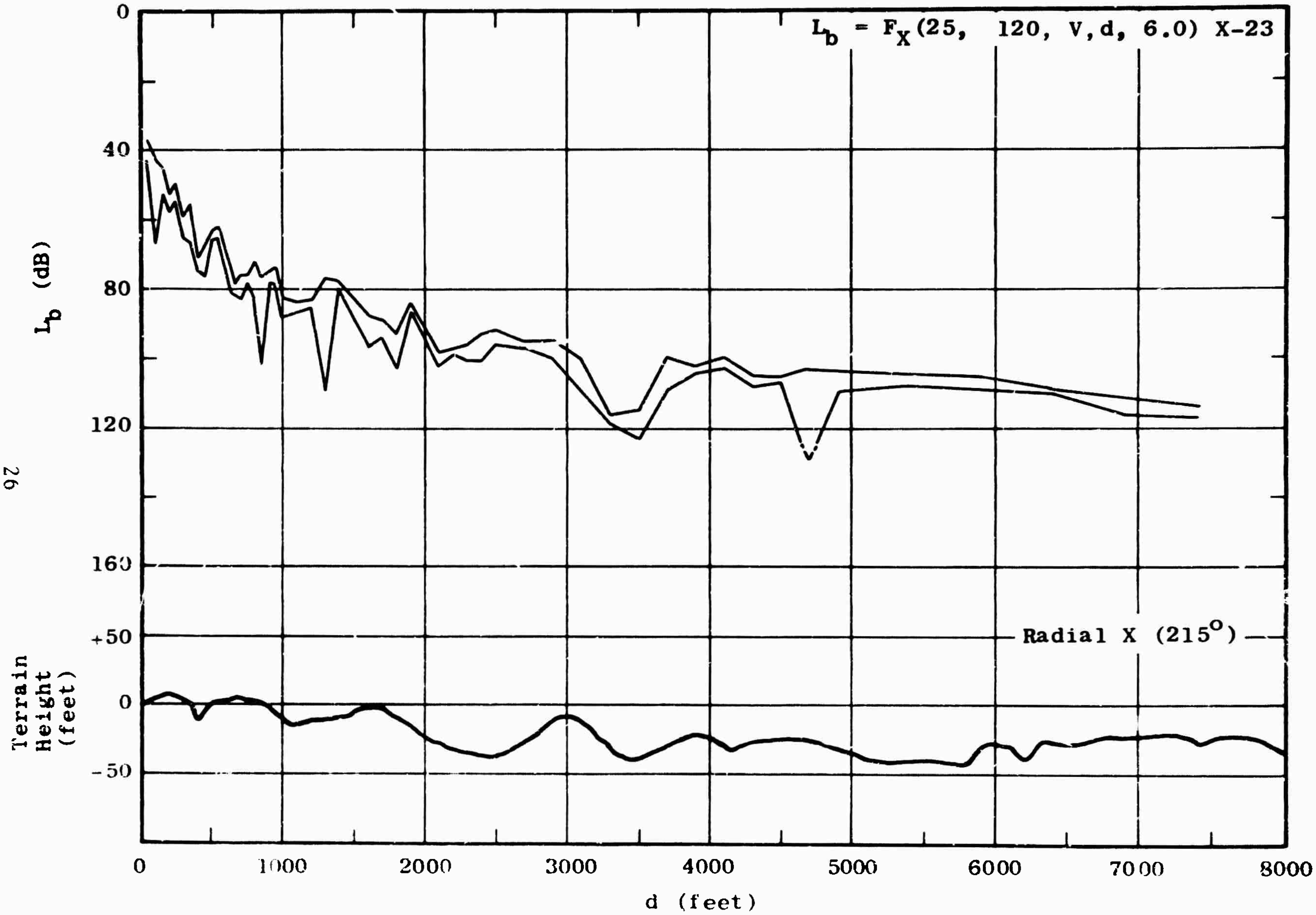

Figure 2.14 Maximum and Minimum Basic Transmission Loss as a Function of Distance

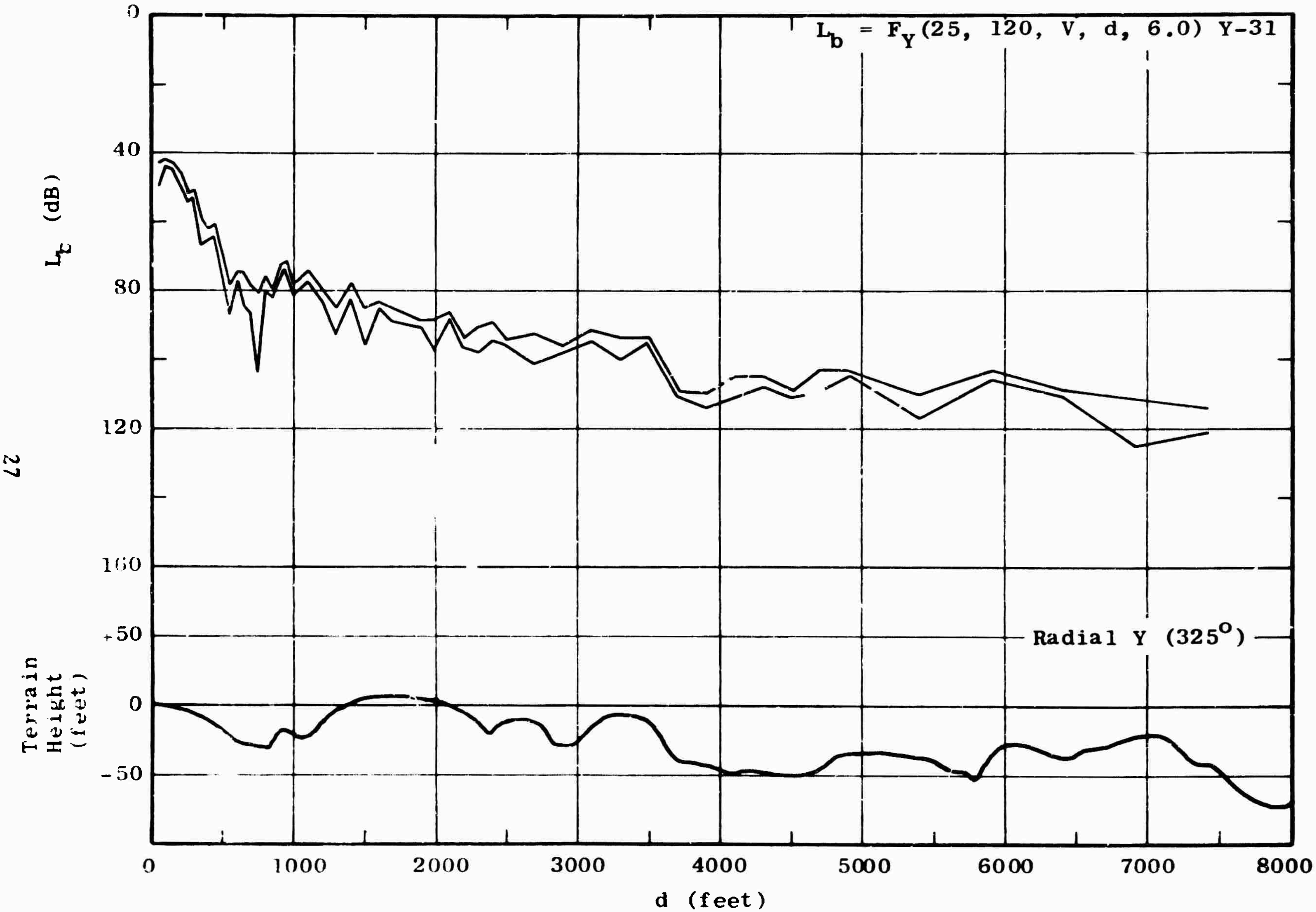

Figure 2.15 Maximum and Minimum Basic Transmission Loss as a Function of Distance

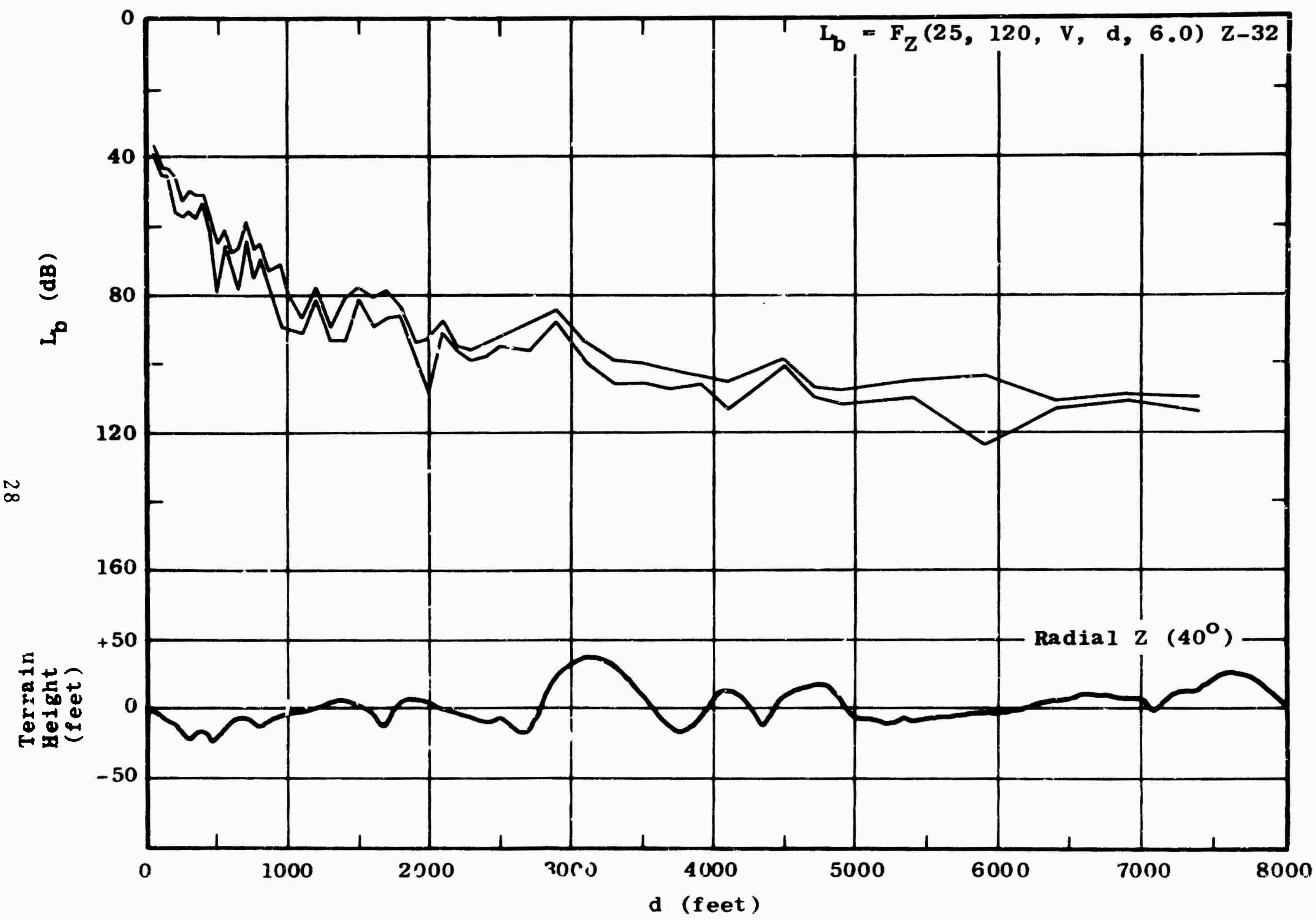

Figure 2.16 Maximum and Minimum Basic Transmission Loss as a Function of Distance

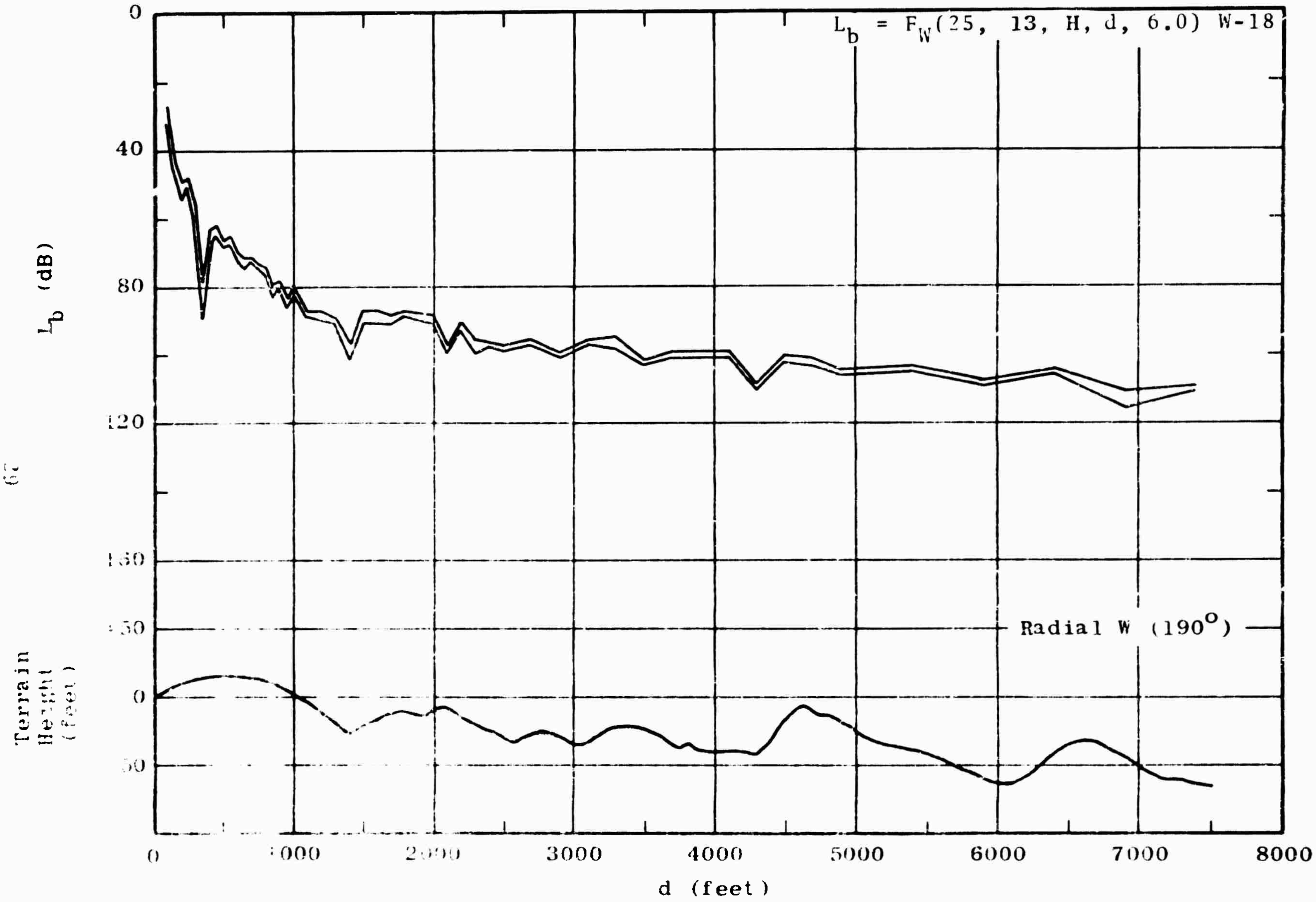

Figure 2.17 Maximum and Minimum Basic Transmission Loss as a Function of Distance

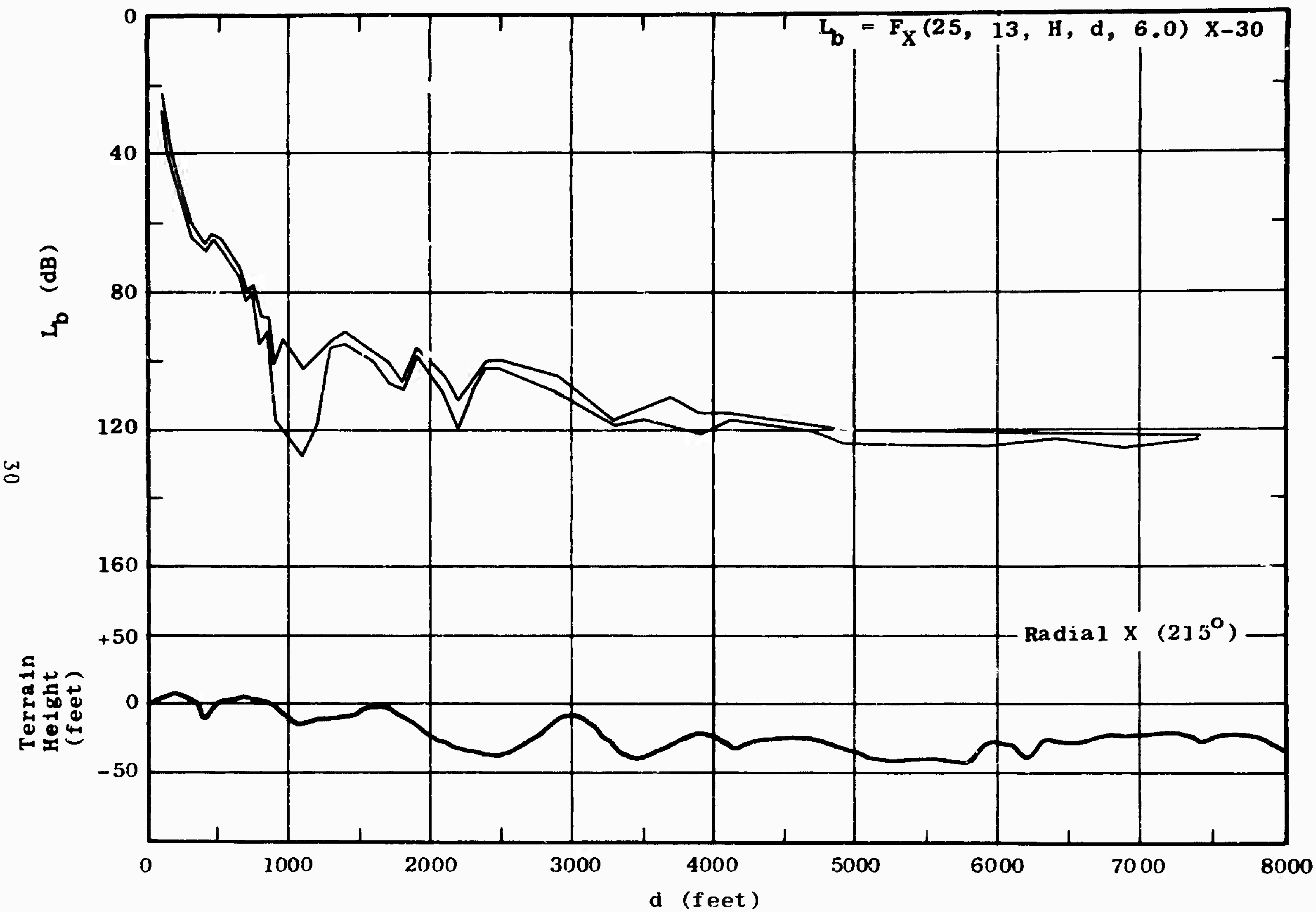

Figure 2.18 Maximum and Minimum Basic Transmission Loss as a Function of Distance

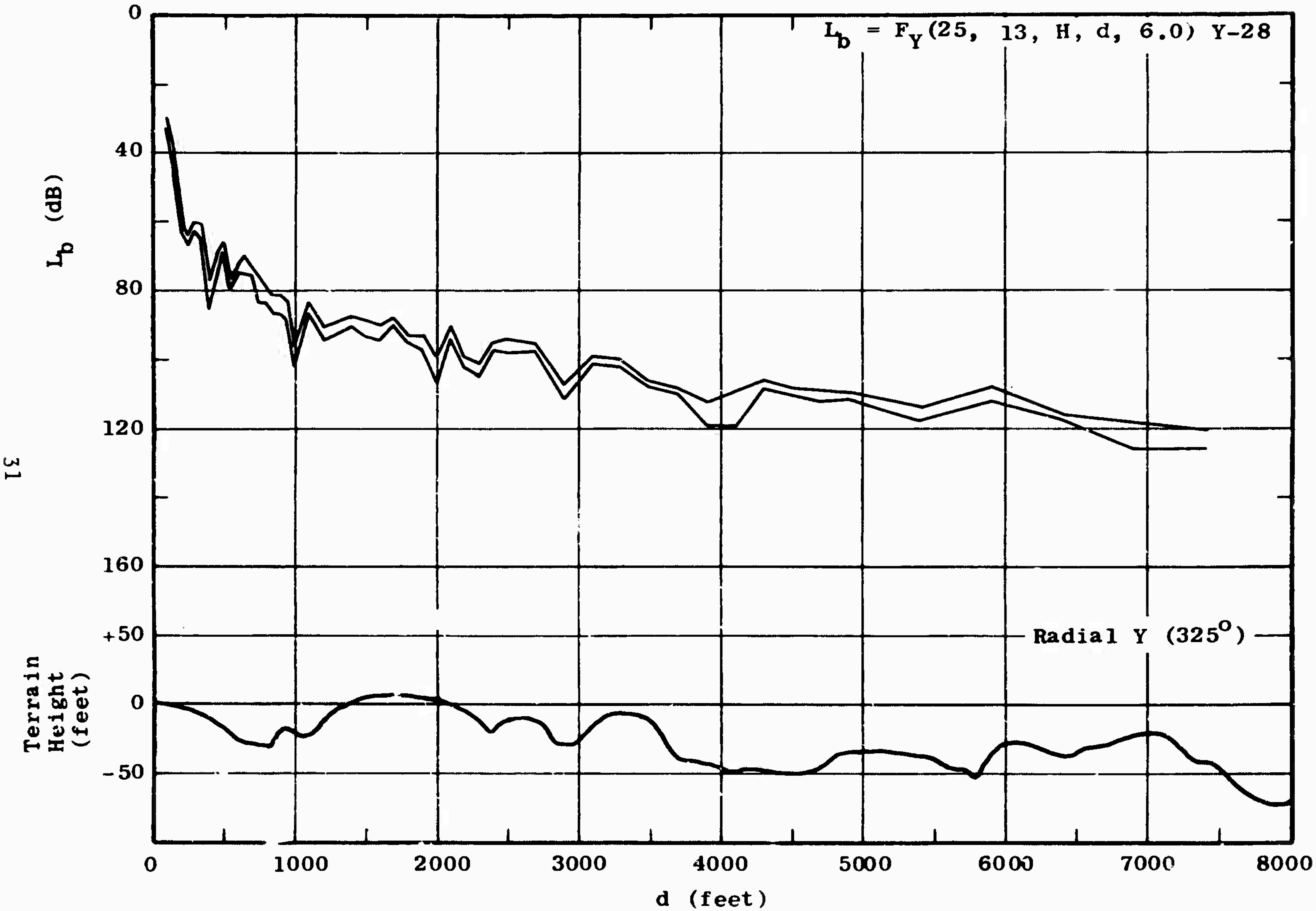

Figure 2.19 Maximum and Minimum Basic Transmission Loss as a Function of Distance

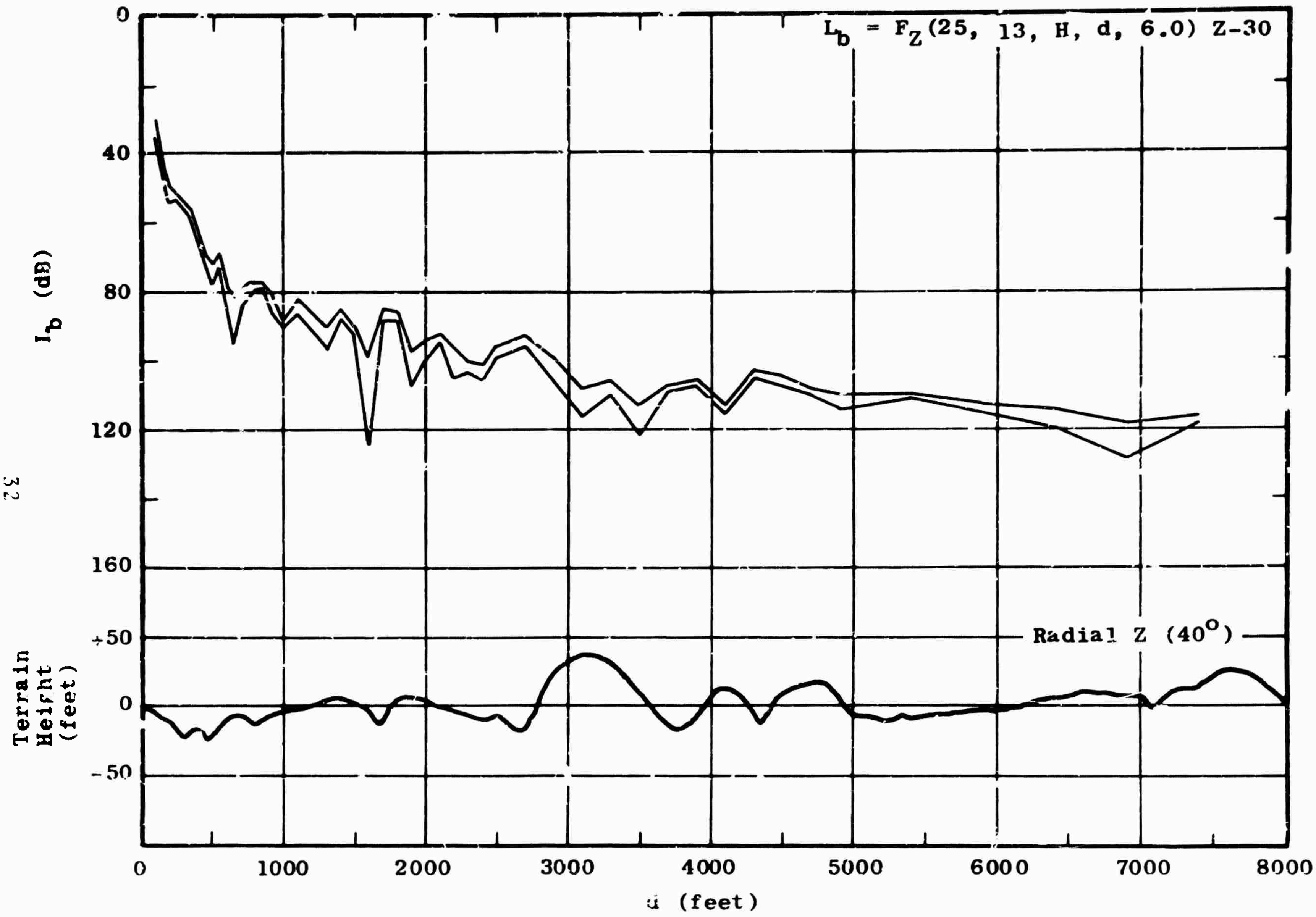

Figure 2.20 Maximum and Minimum Basic Transmission Loss as a Function of Distance

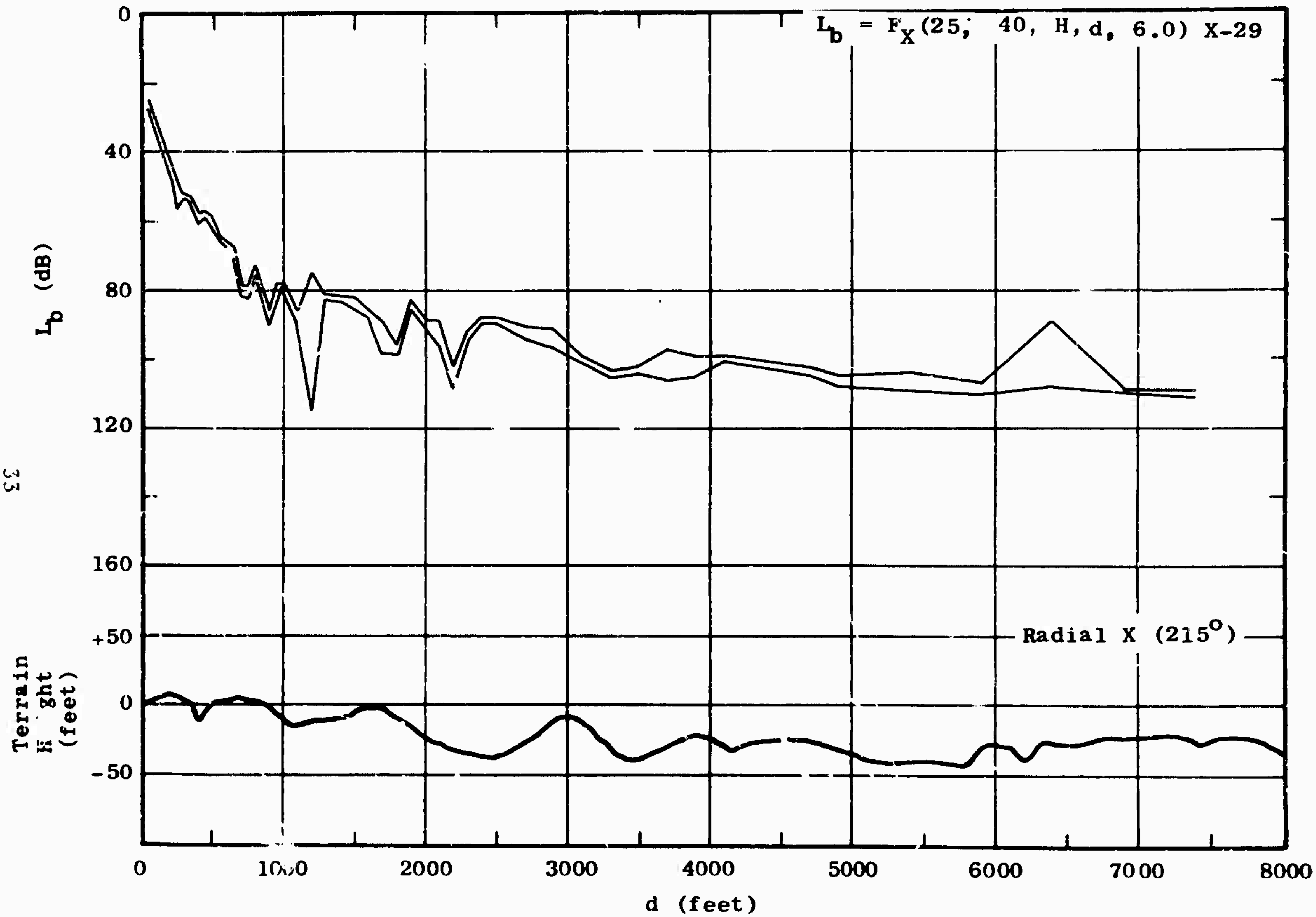

Figure 2.21 Maximum and Minimum Basic Transmission Loss as a Function of Distance

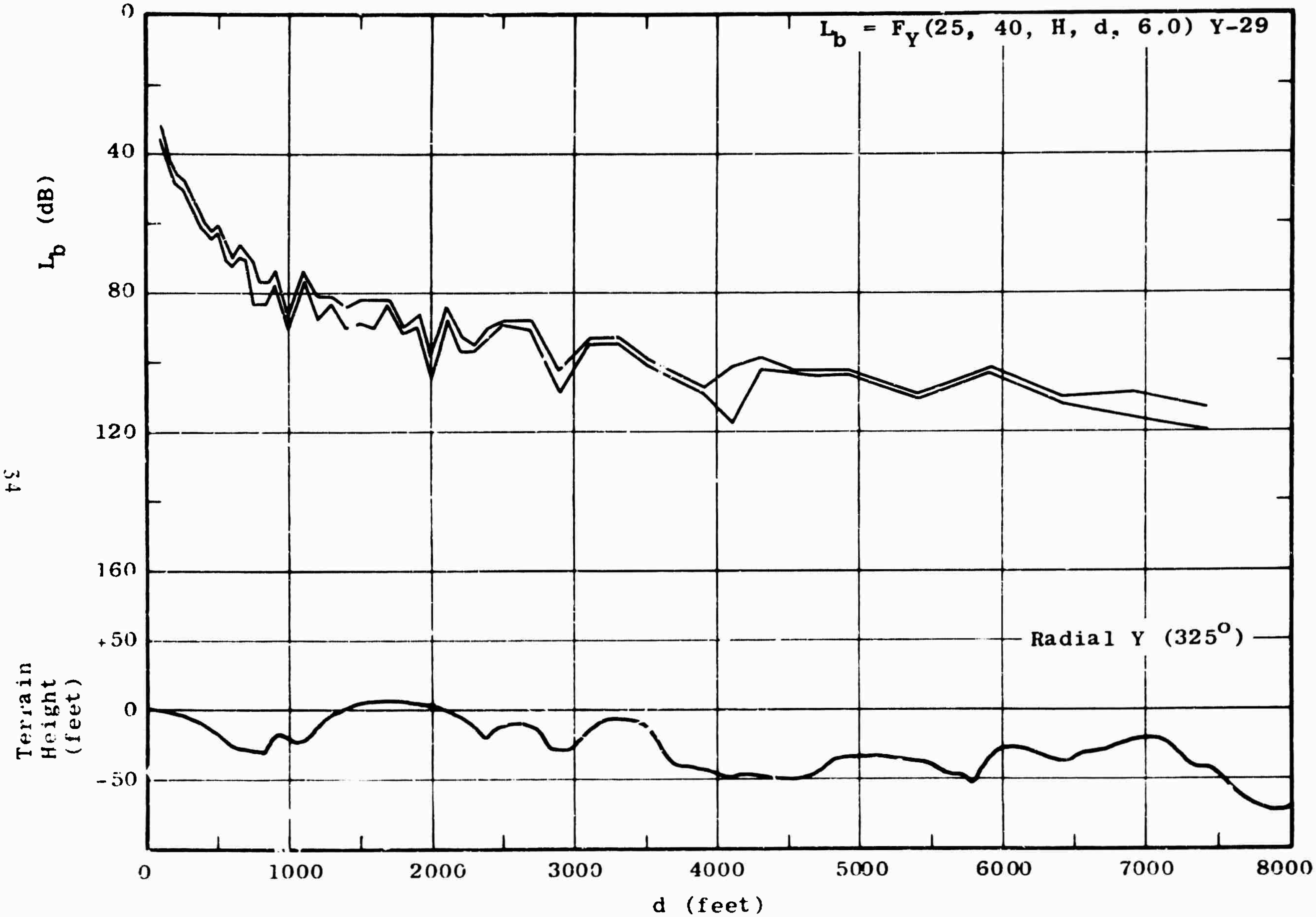

Figure 2.22 Maximum and Minimum Basic Transmission Loss as a Function of Distance

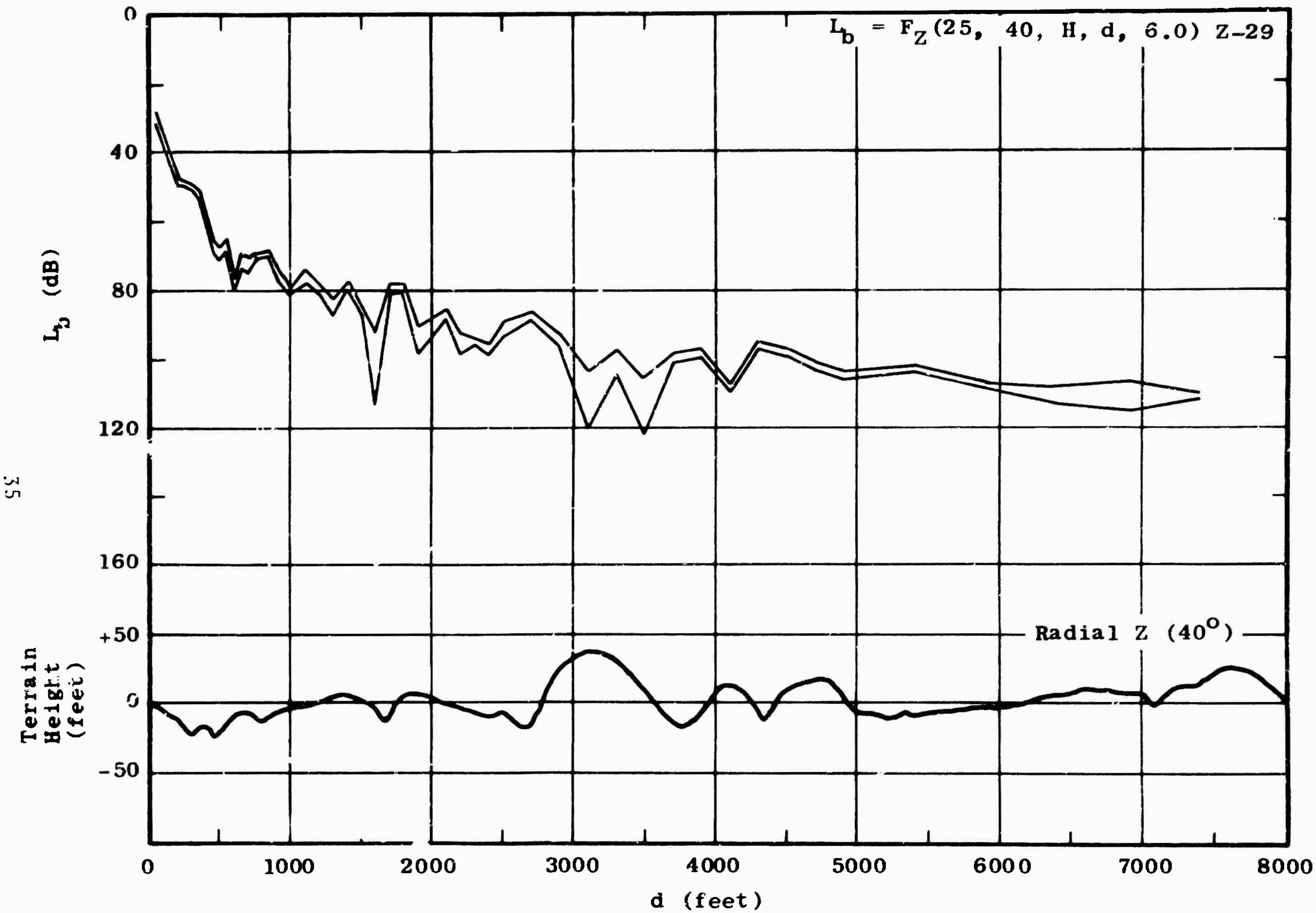

Figure 2.23 Maximum and Minimum Basic Transmission Loss as a Function of Distance

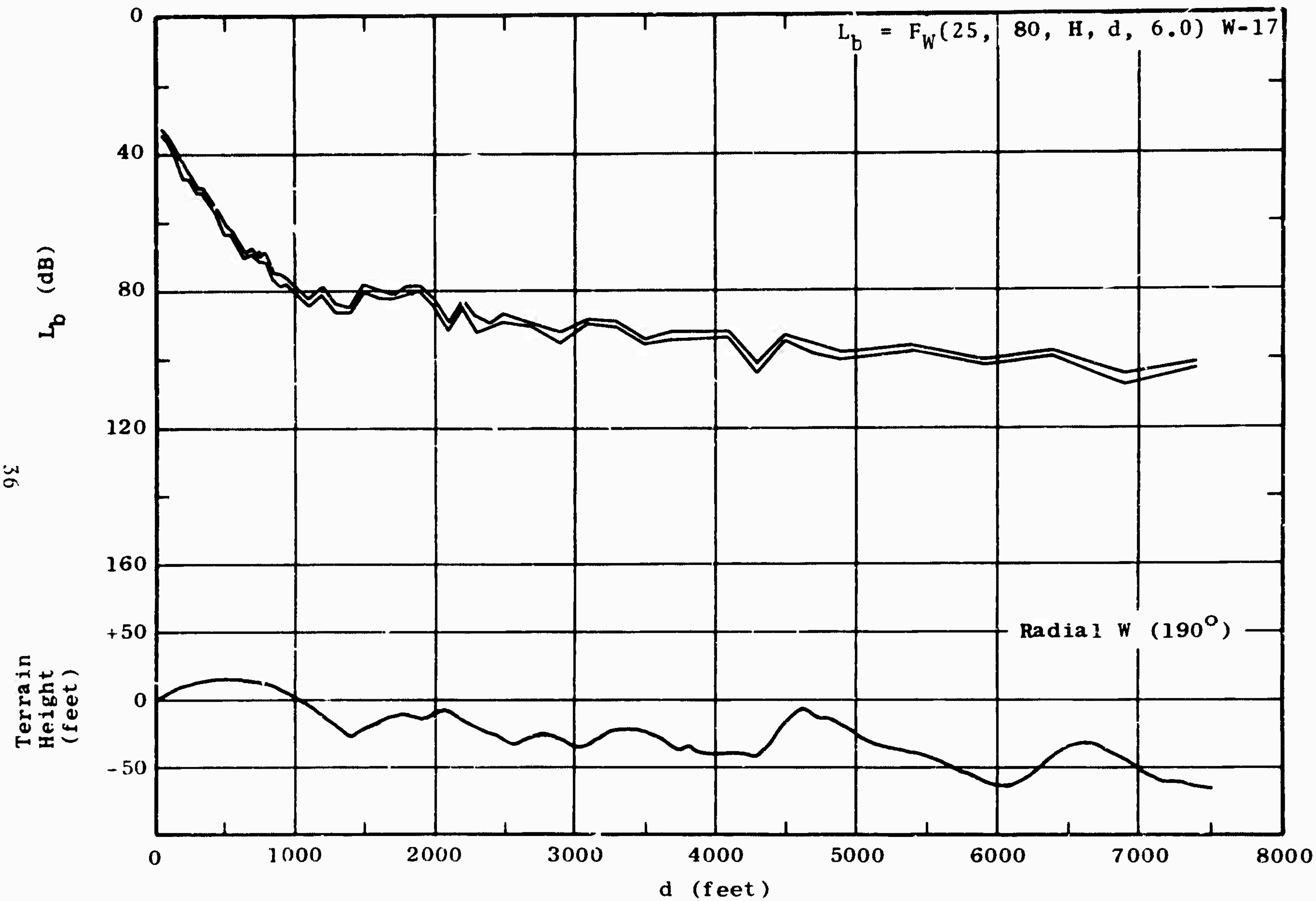

Figure 2.24 Maximum and Minimum Basic Transmission Loss as a Function of Distance

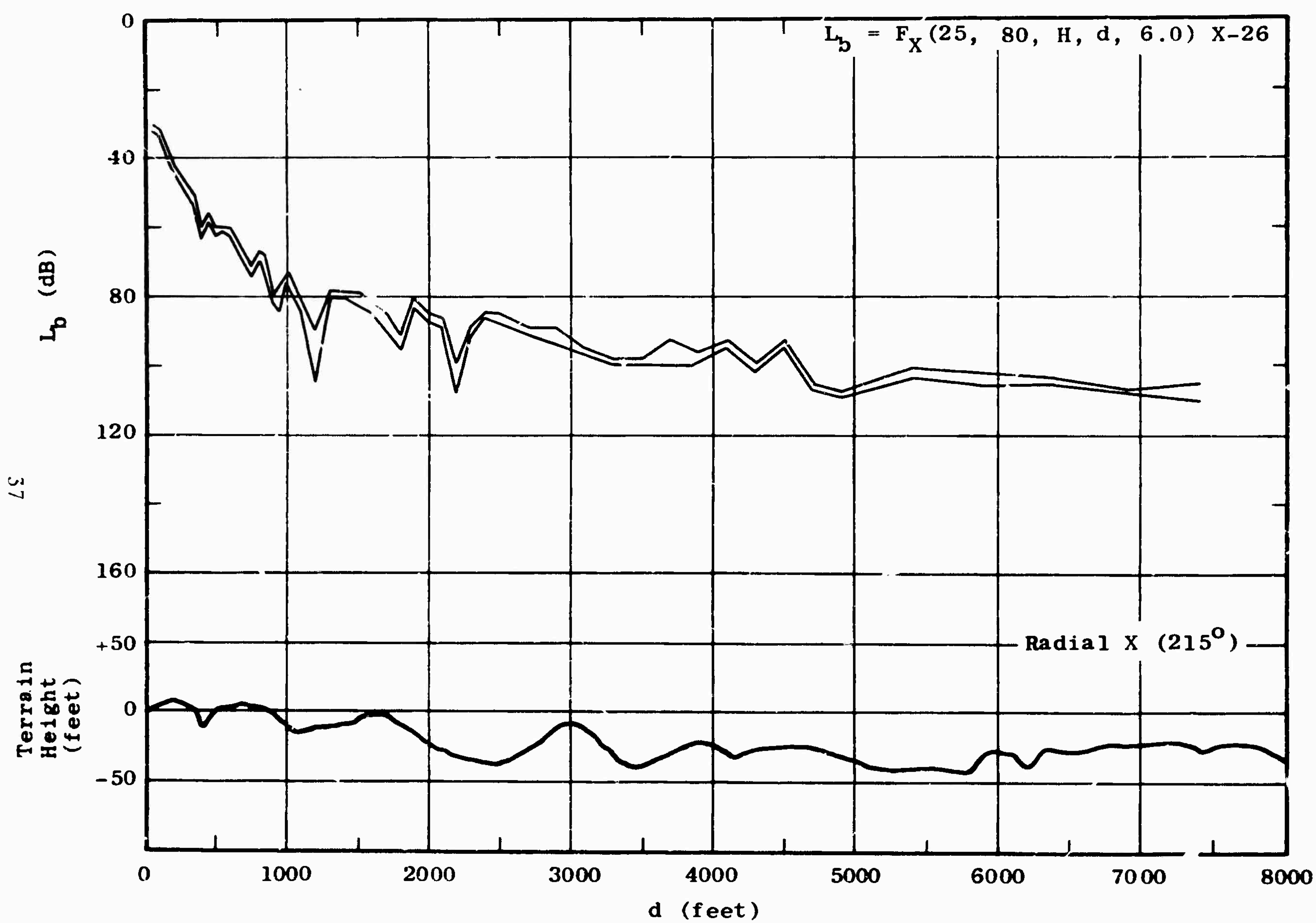

Figure 2.25 Maximum and Minimum Basic Transmission Loss as a Function of Distance

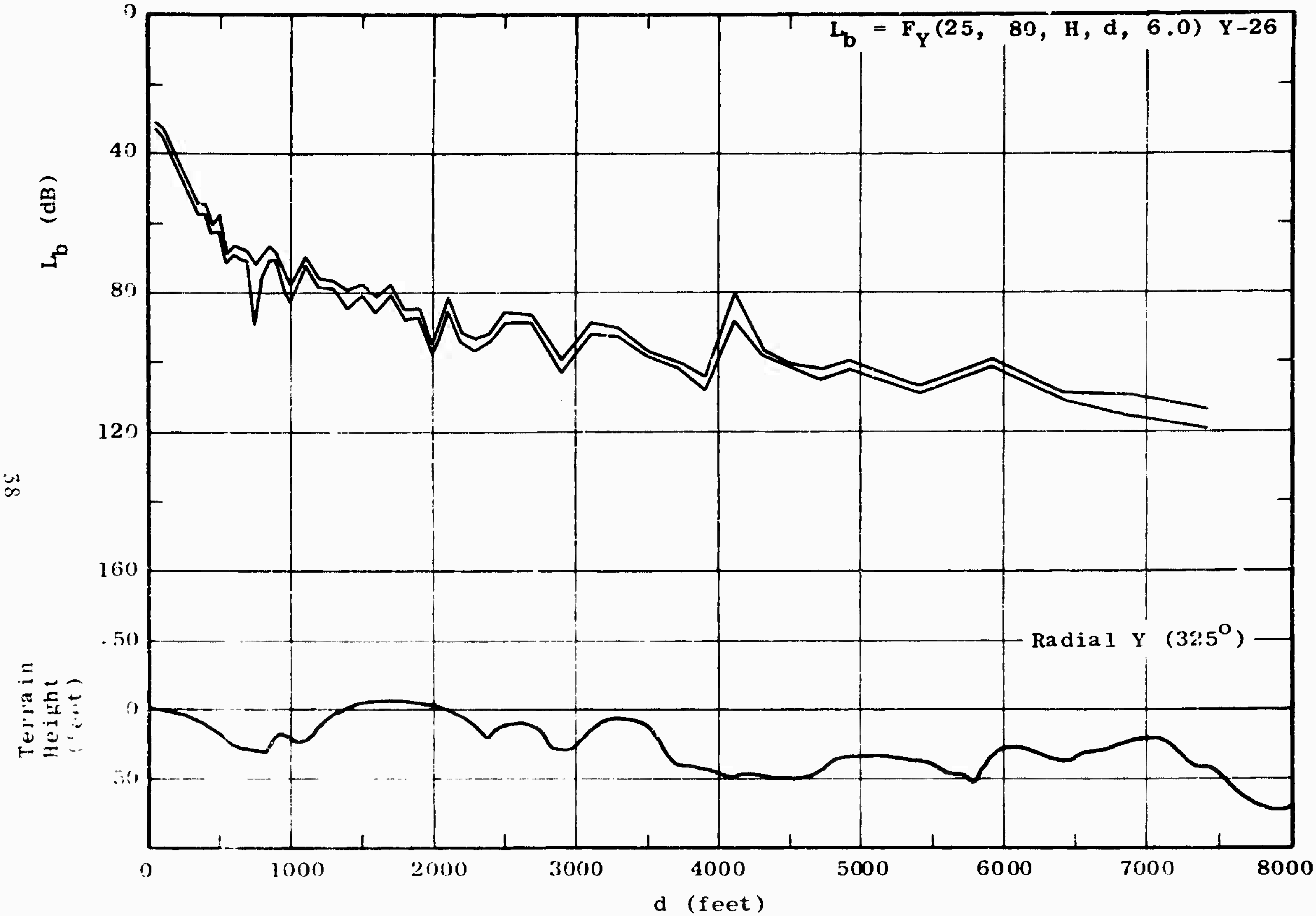

Figure 2.26 Maximum and Minimum Basic Transmission Loss as a Function of Distance

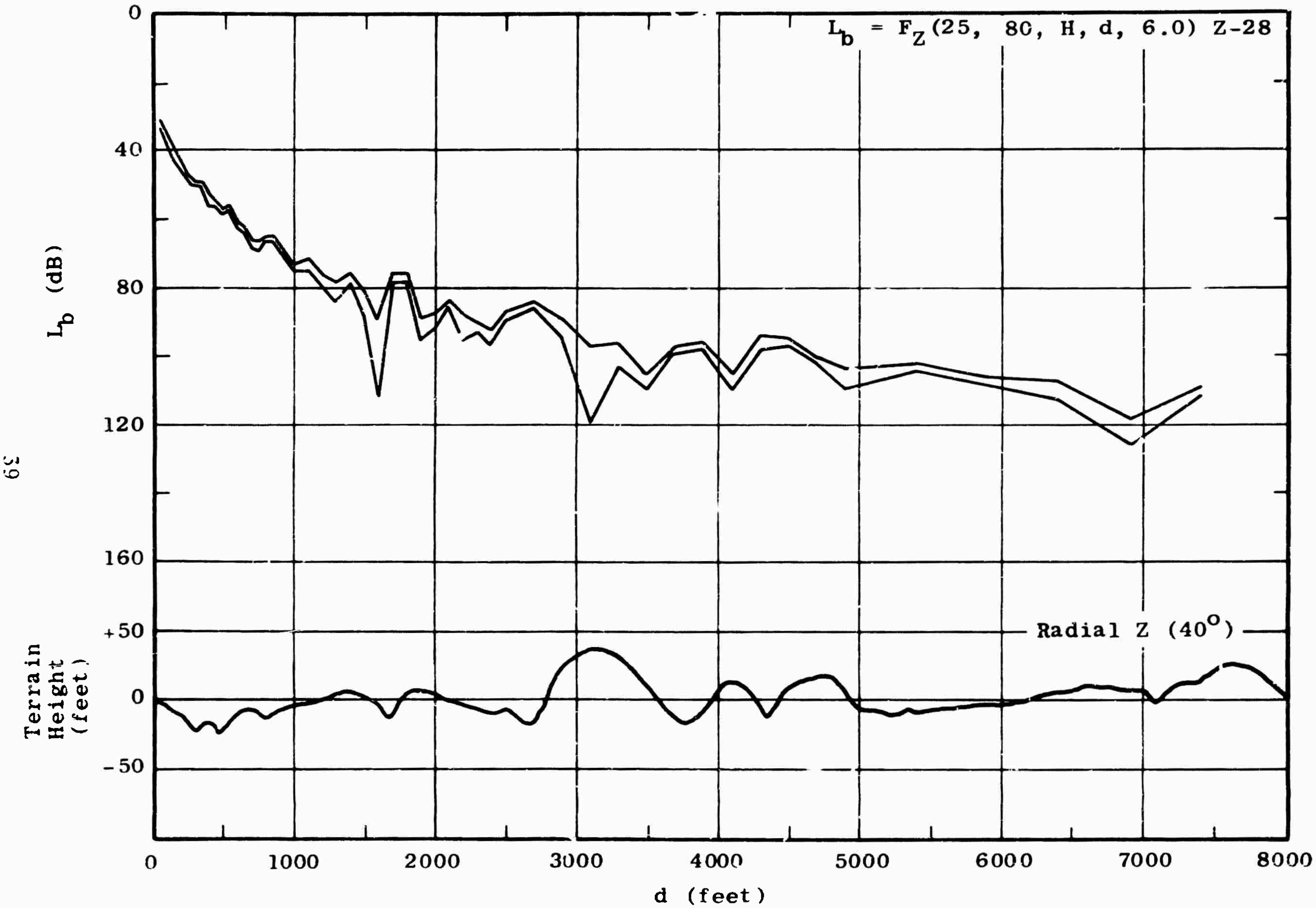

Figure 2.27 Maximum and Minimum Basic Transmission Loss as a Function of Distance

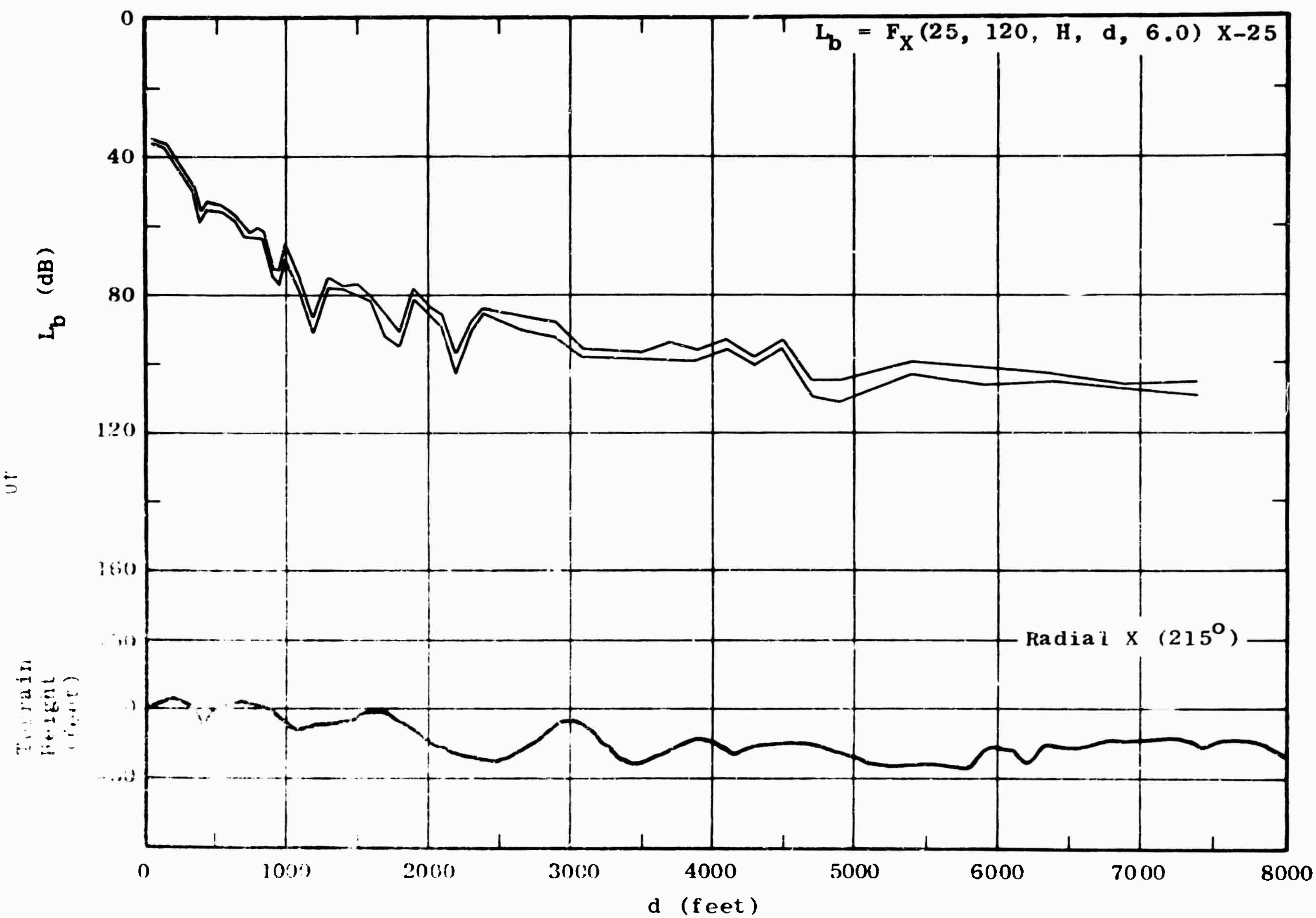

Figure 2.28 Maximum and Minimum Basic Transmission Loss as a Function of Distance

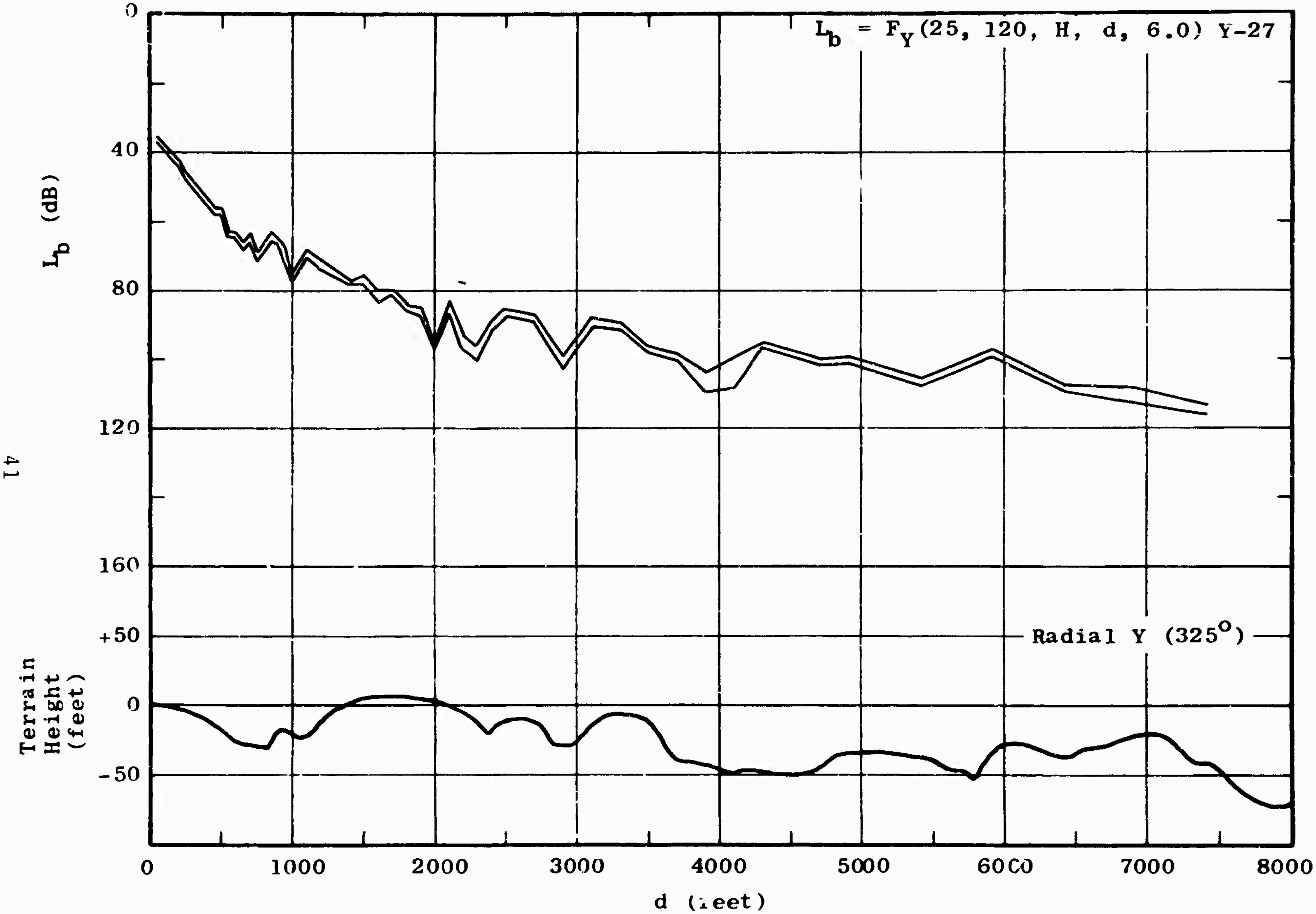

Figure 2.29 Maximum and Minimum Basic Transmission Loss as a Function of Distance

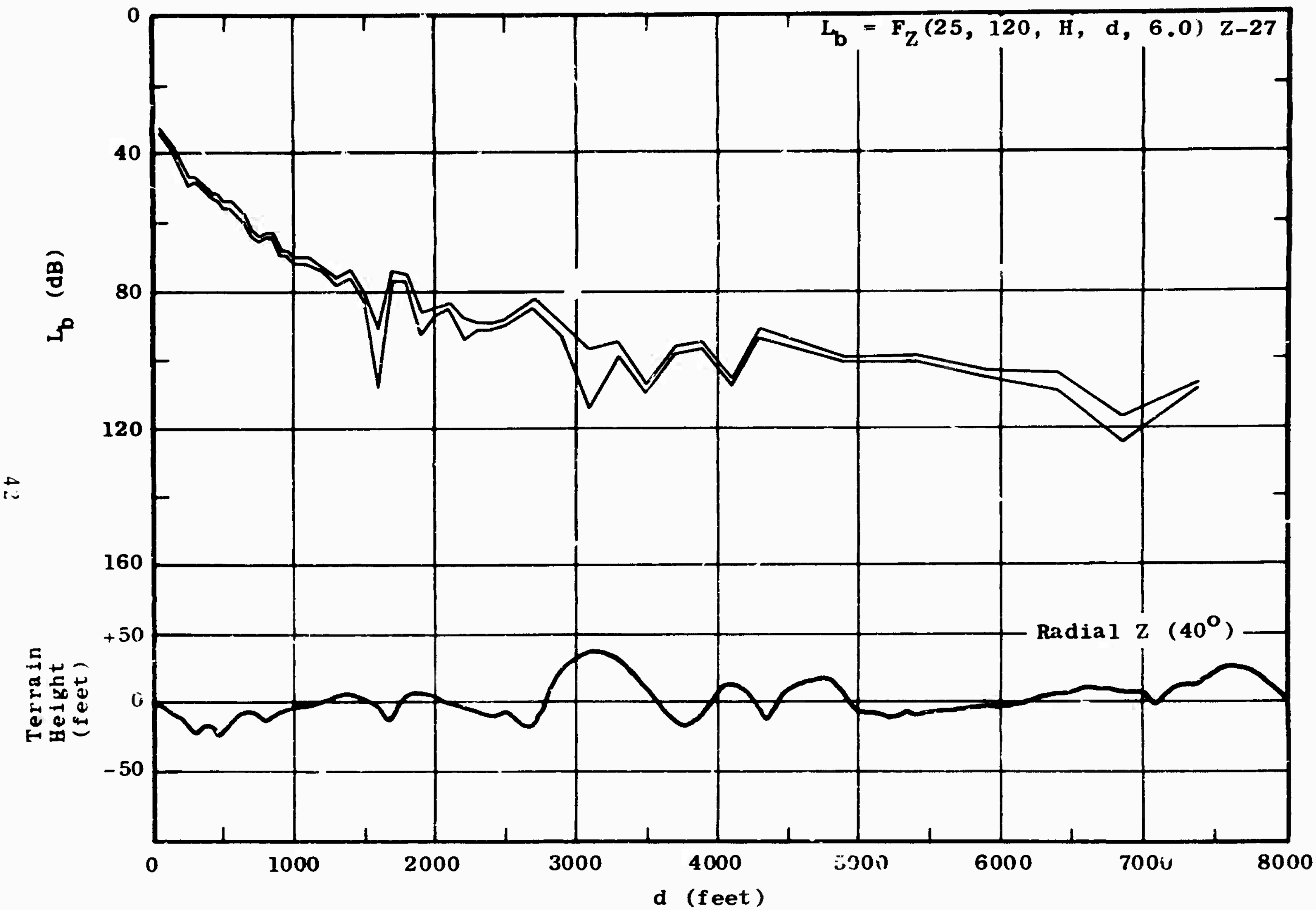

Figure 2.30 Maximum and Minimum Basic Transmission Loss as a Function of Distance

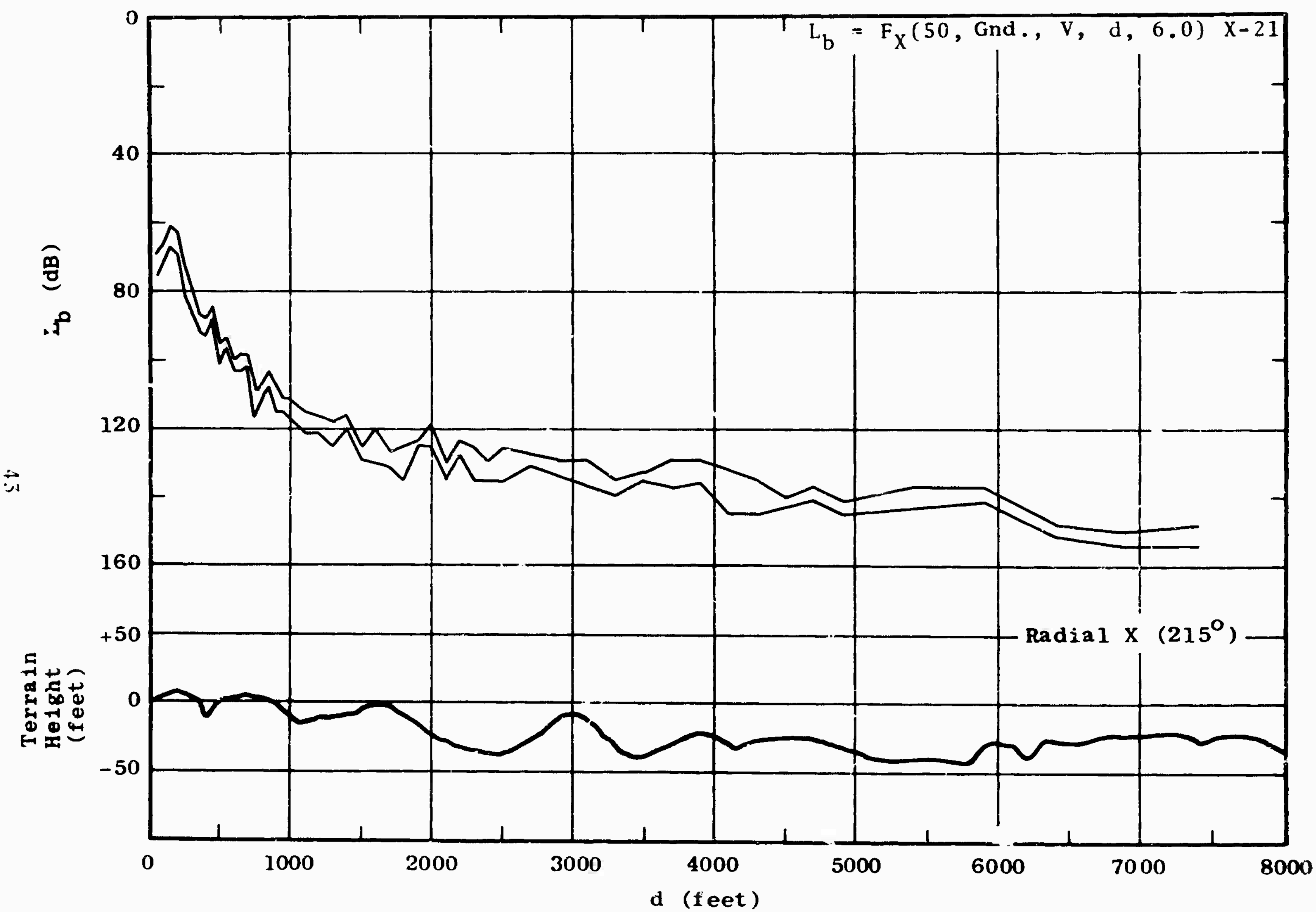

Figure 2.31 Maximum and Minimum Basic Transmission Loss as a Function of Distance

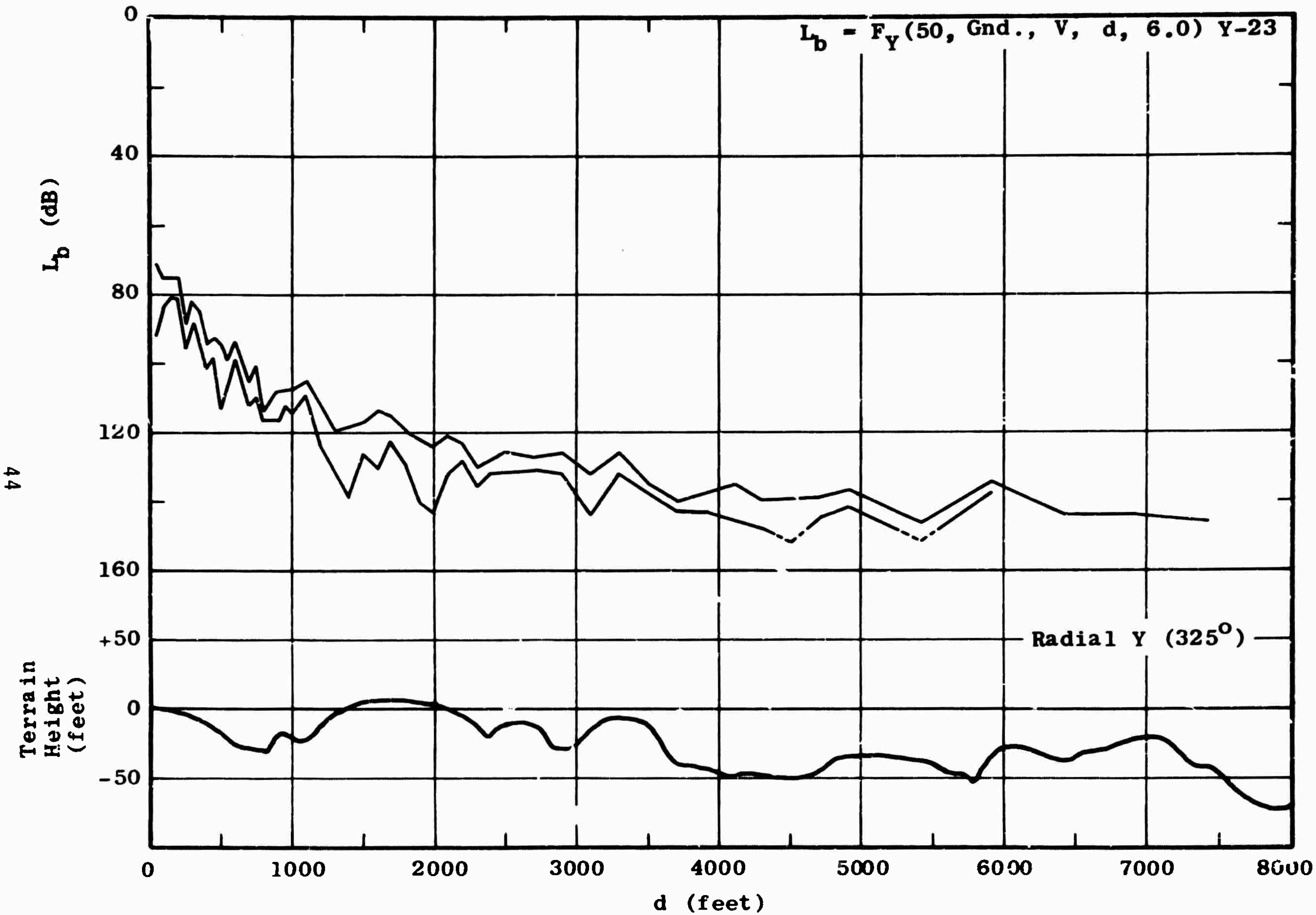

Figure 2.32 Maximum and Minimum Basic Transmission Loss as a Function of Distance

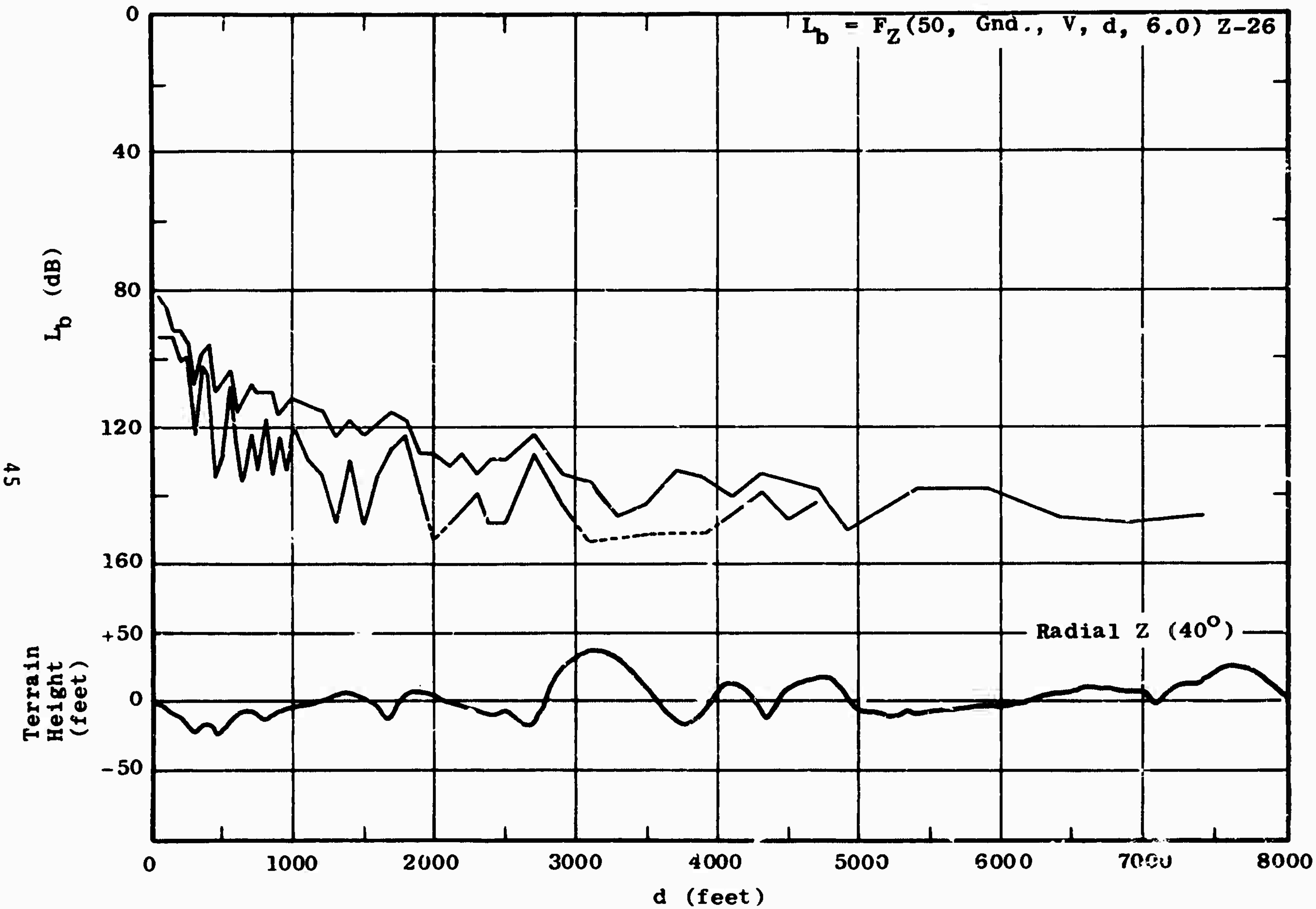

Figure 2.33 Maximum and Minimum Basic Transmission Loss as a Function of Distance

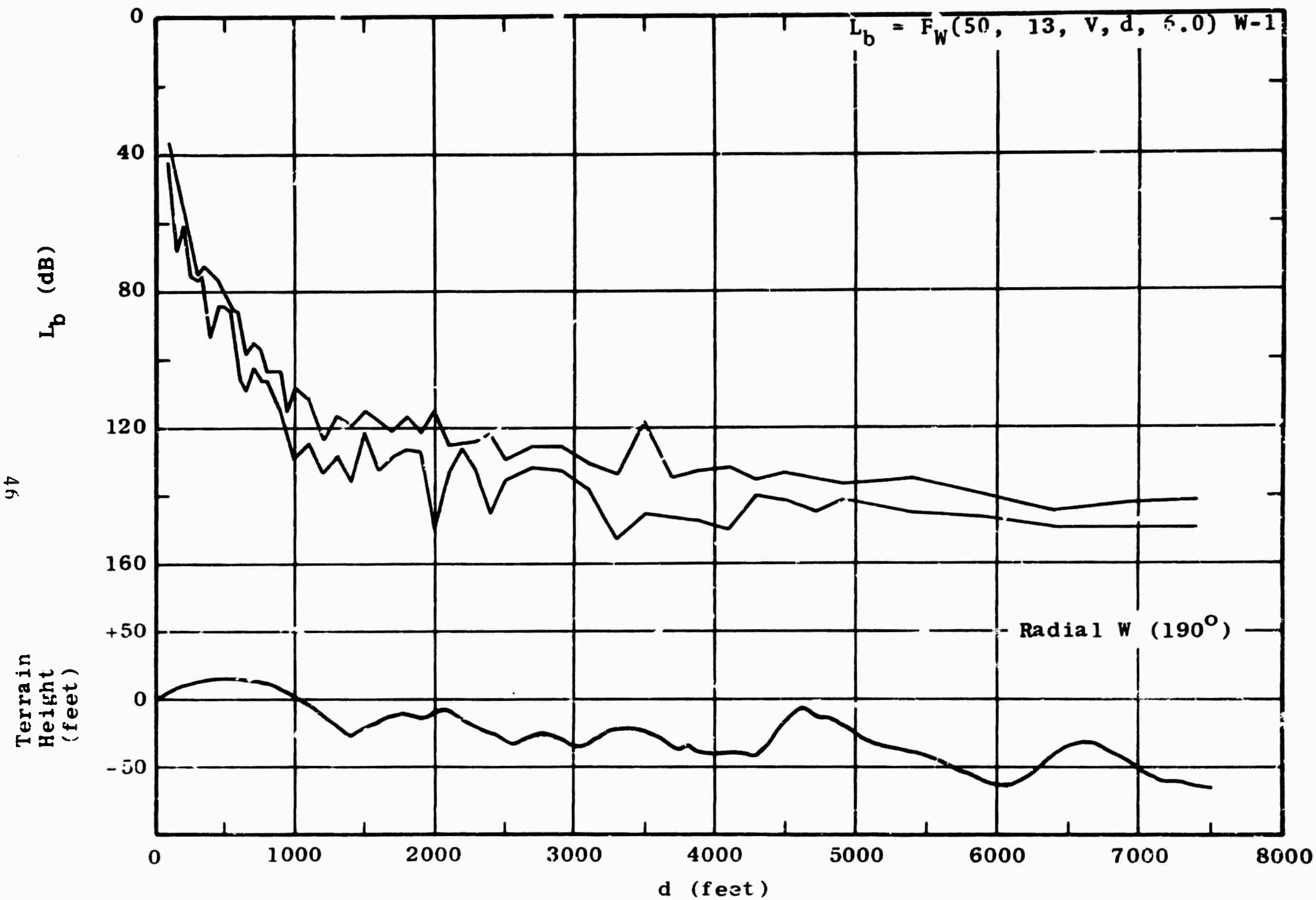

Figure 2.34 Maximum and Minimum Basic Transmission Loss as a Function of Distance

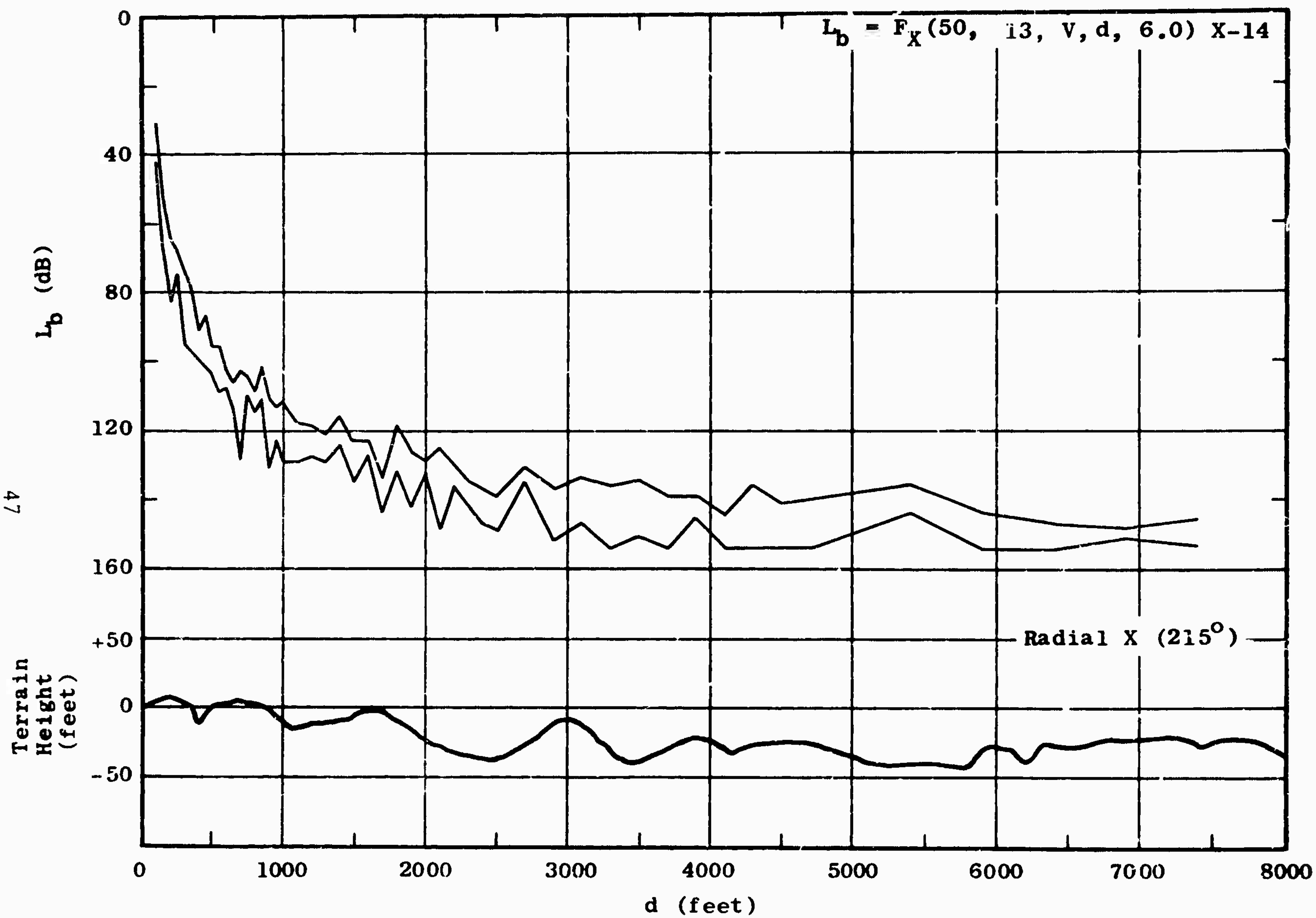

Figure 2.35 Maximum and Minimum Basic Transmission Loss as · Function of Distance

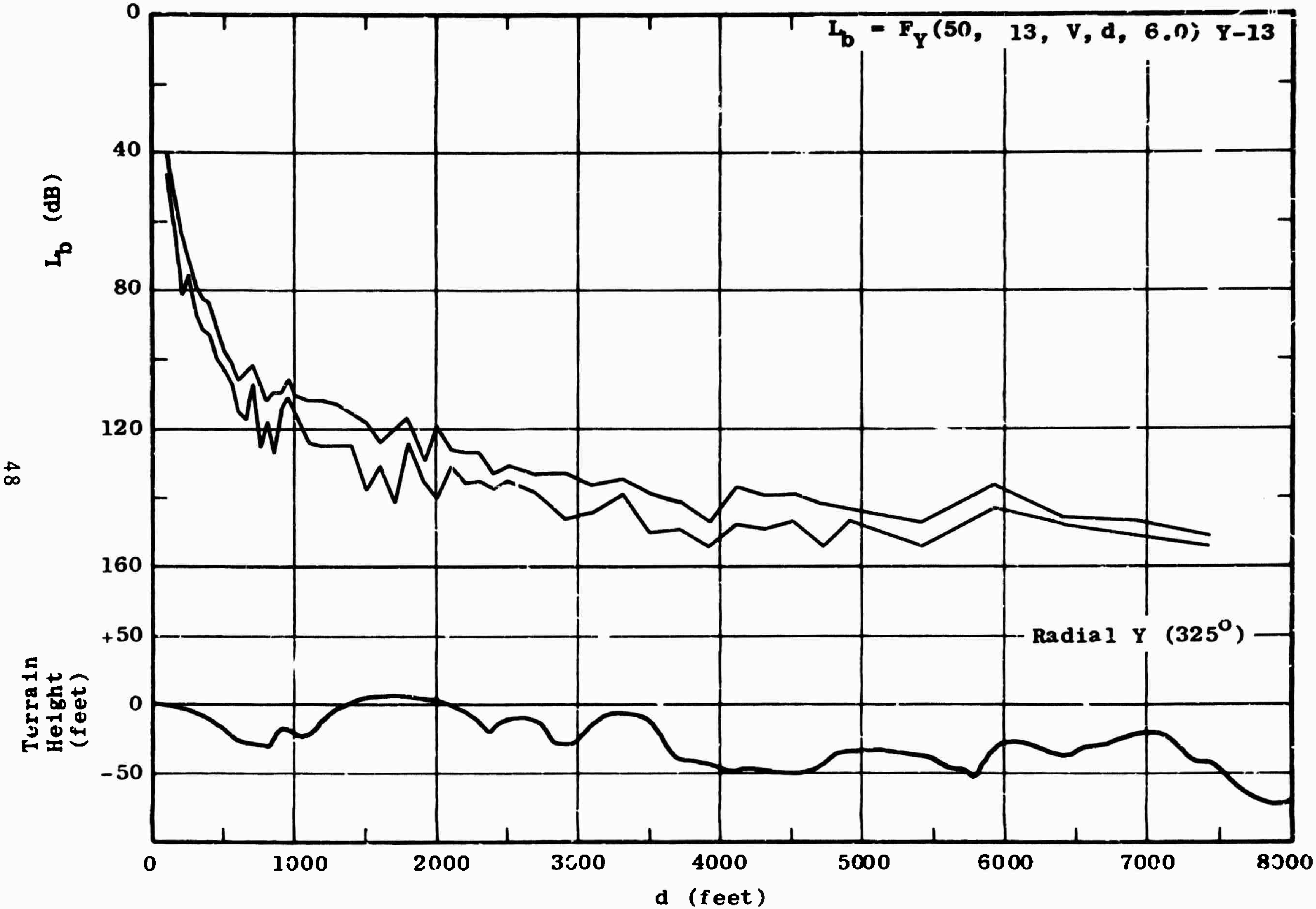

Figure 2.36 Maximum and Minimum Basic Transmission Loss as a Function of Distance

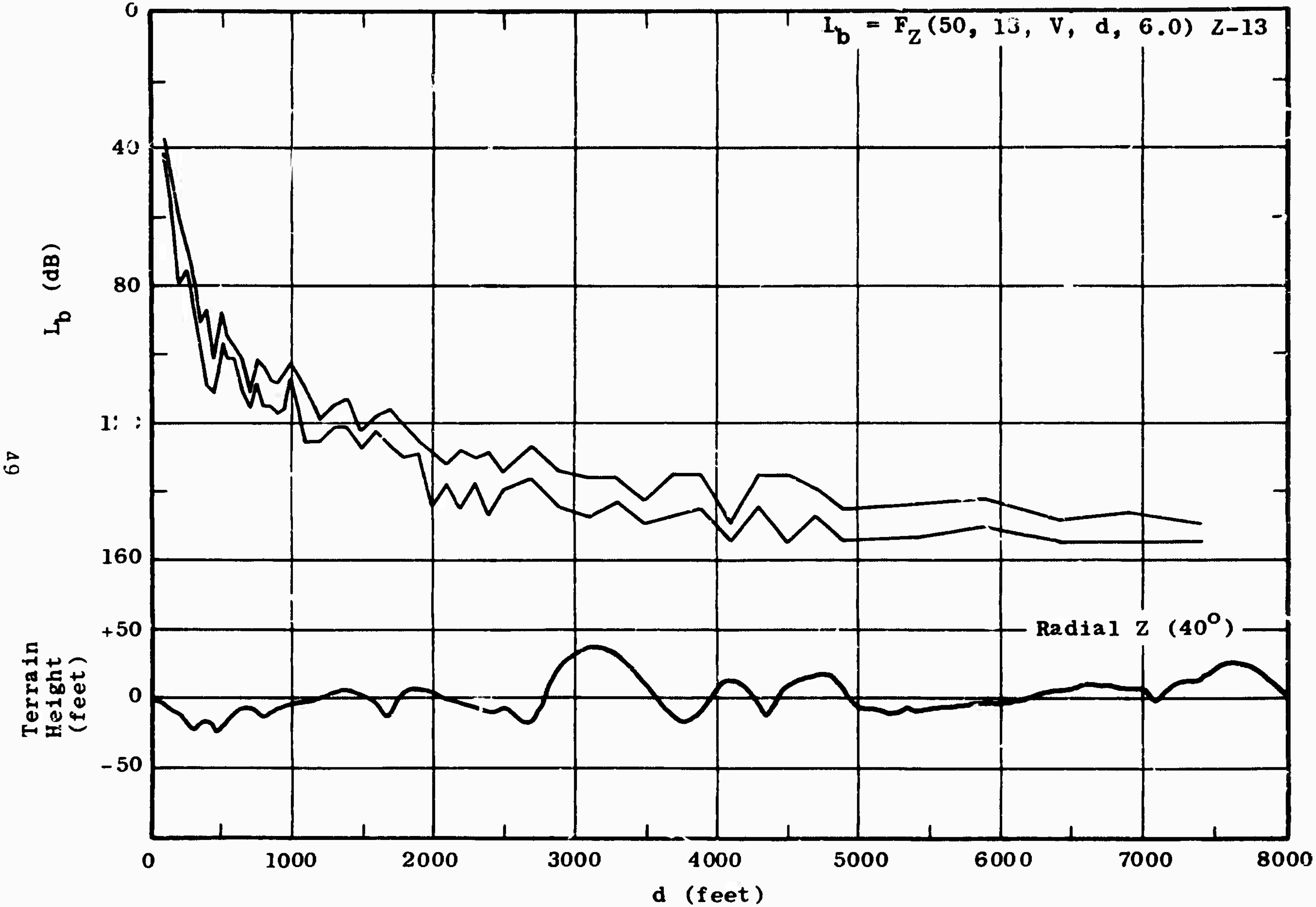

Figure 2.37 Maximum and Minimum Basic Transmission Loss as a Function of Distance

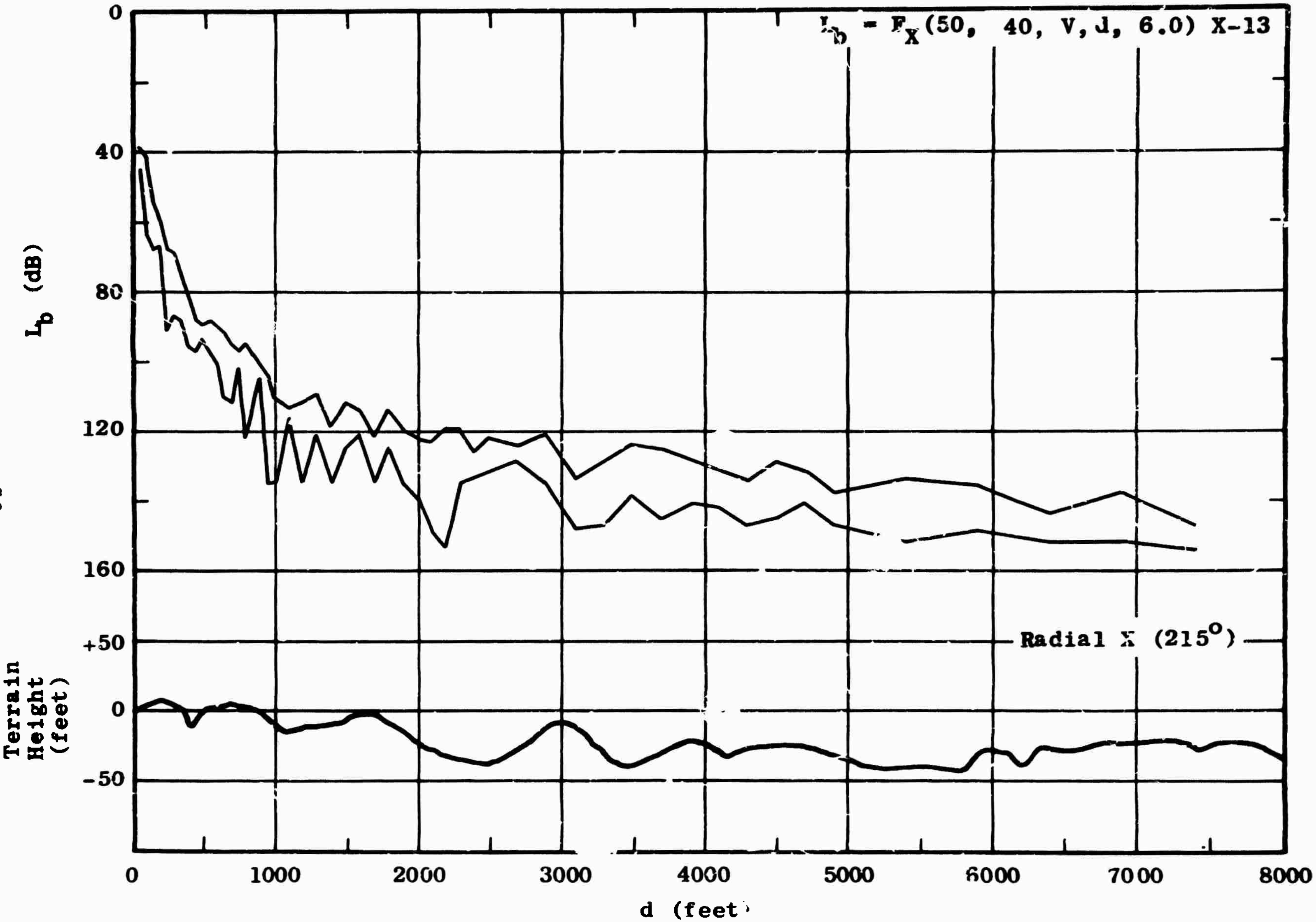

Figure 2.38 Maximum and Minimum Basic Transmission Loss as a Function of Distance

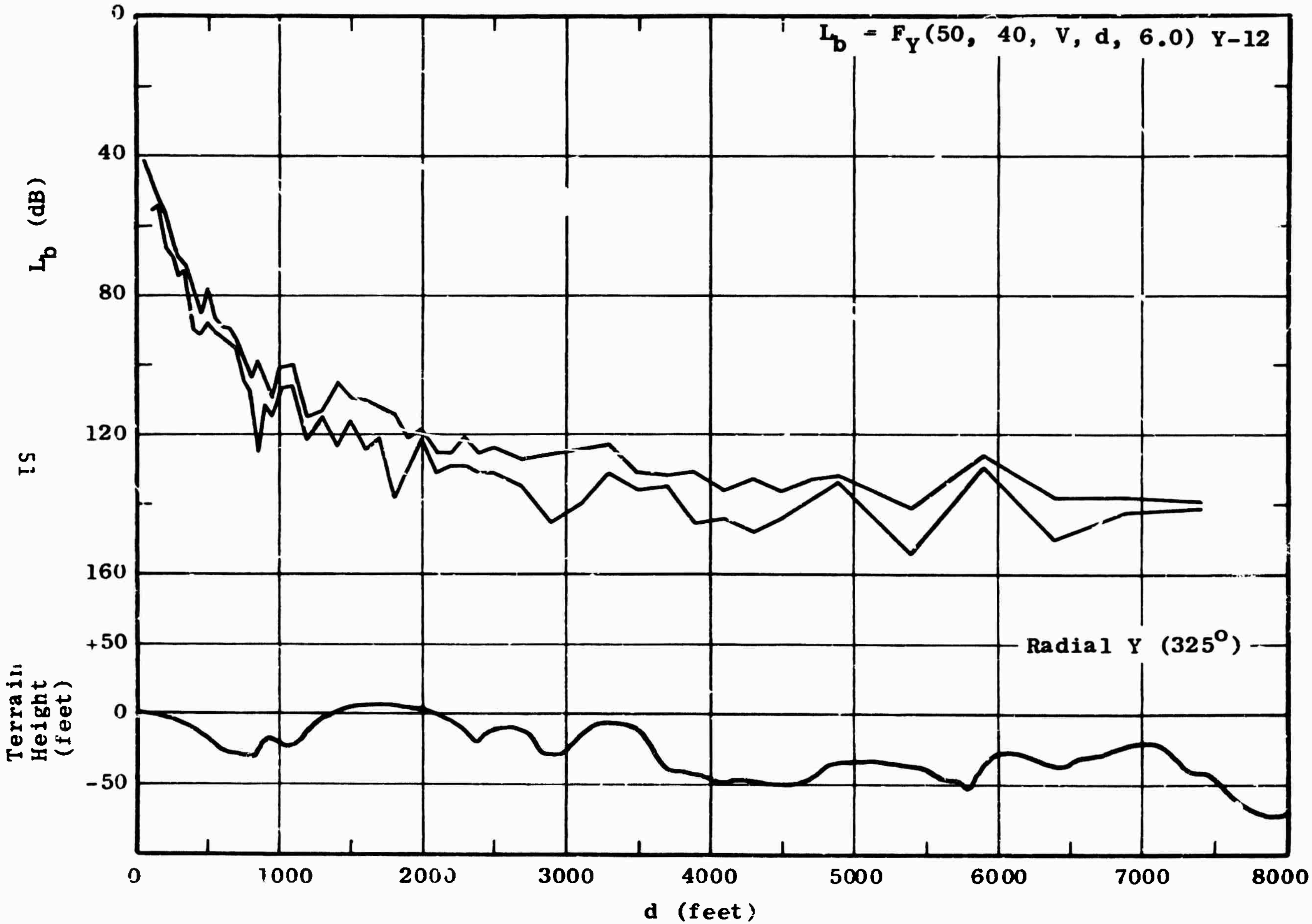

Figure 2.39 Maximum and Minimum Basic Transmission Loss as a Function of Distance

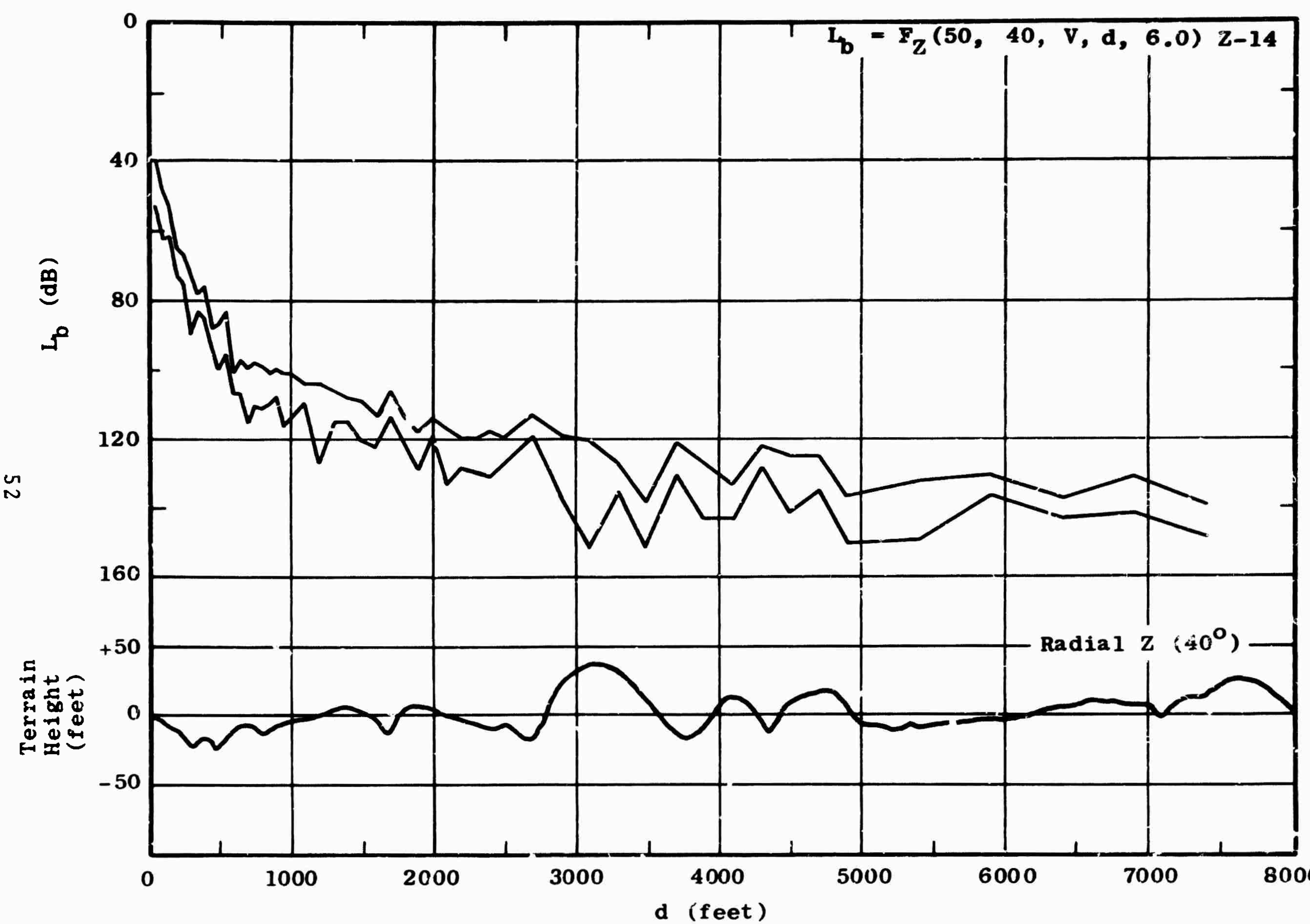

Figure 2.40 Maximum and Minimum Basic Transmission Loss as a Function of Distance

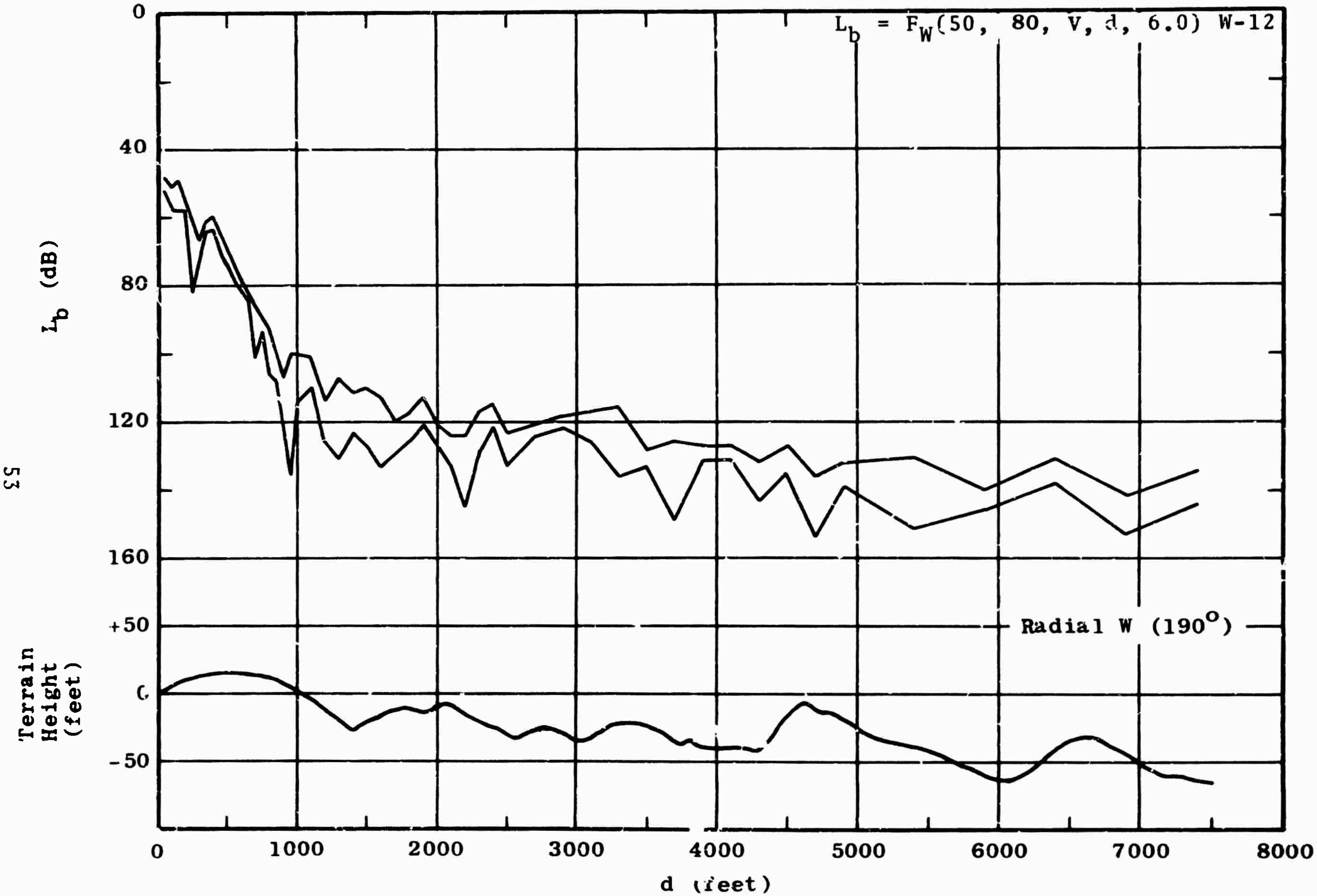

Figure 2.41 Maximum and Minimum Basic Transmission Loss as a Function of Distance

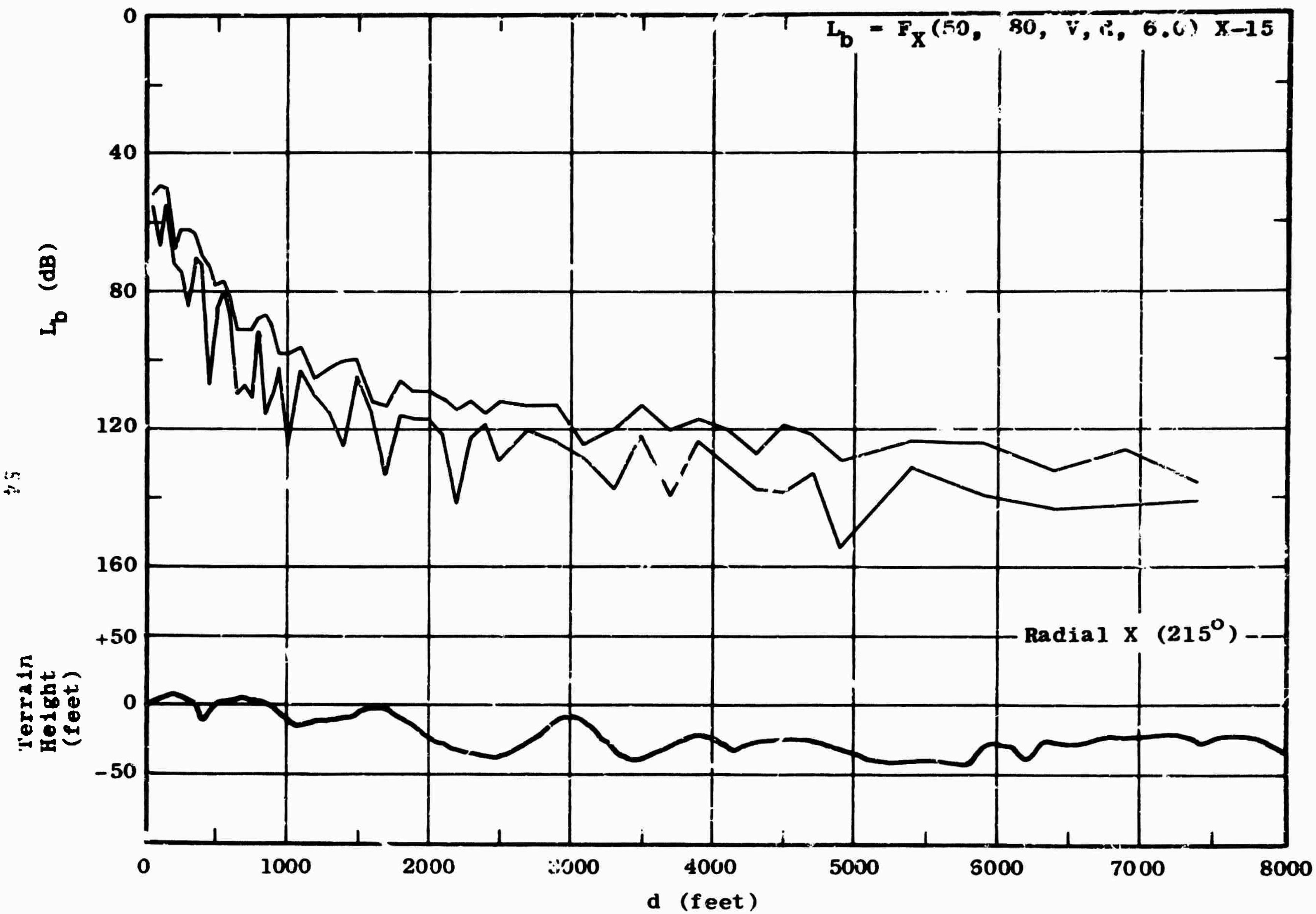

Figure 2.42 Maximum and Minimum Basic Transmission Loss as a Function of Distance

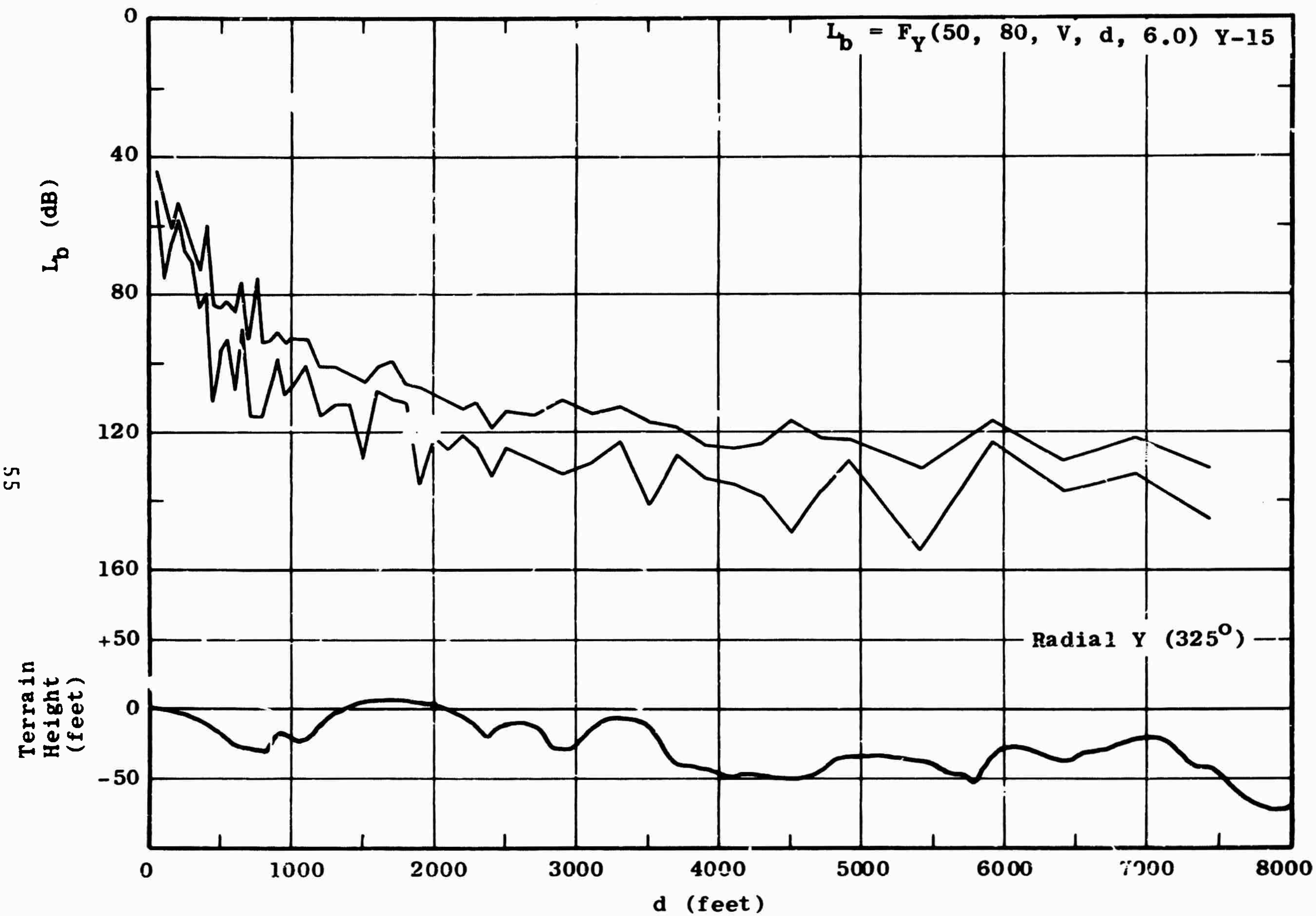

Figure 2.43 Maximum and Minimum Basic Transmission Loss as a Function of Distance

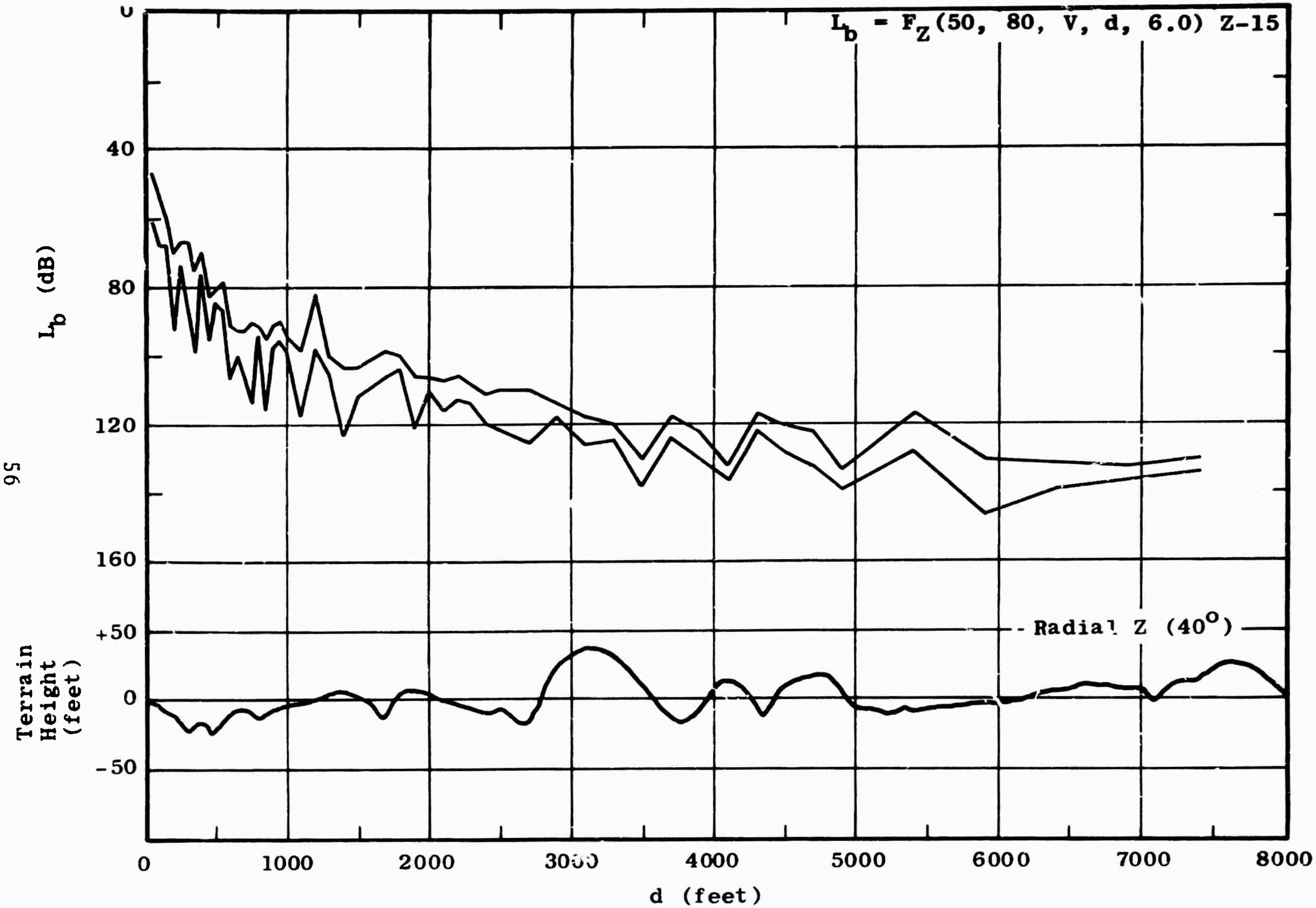

Figure 2.44 Maximum and Minimum Basic Transmission Loss as a Function of Distance

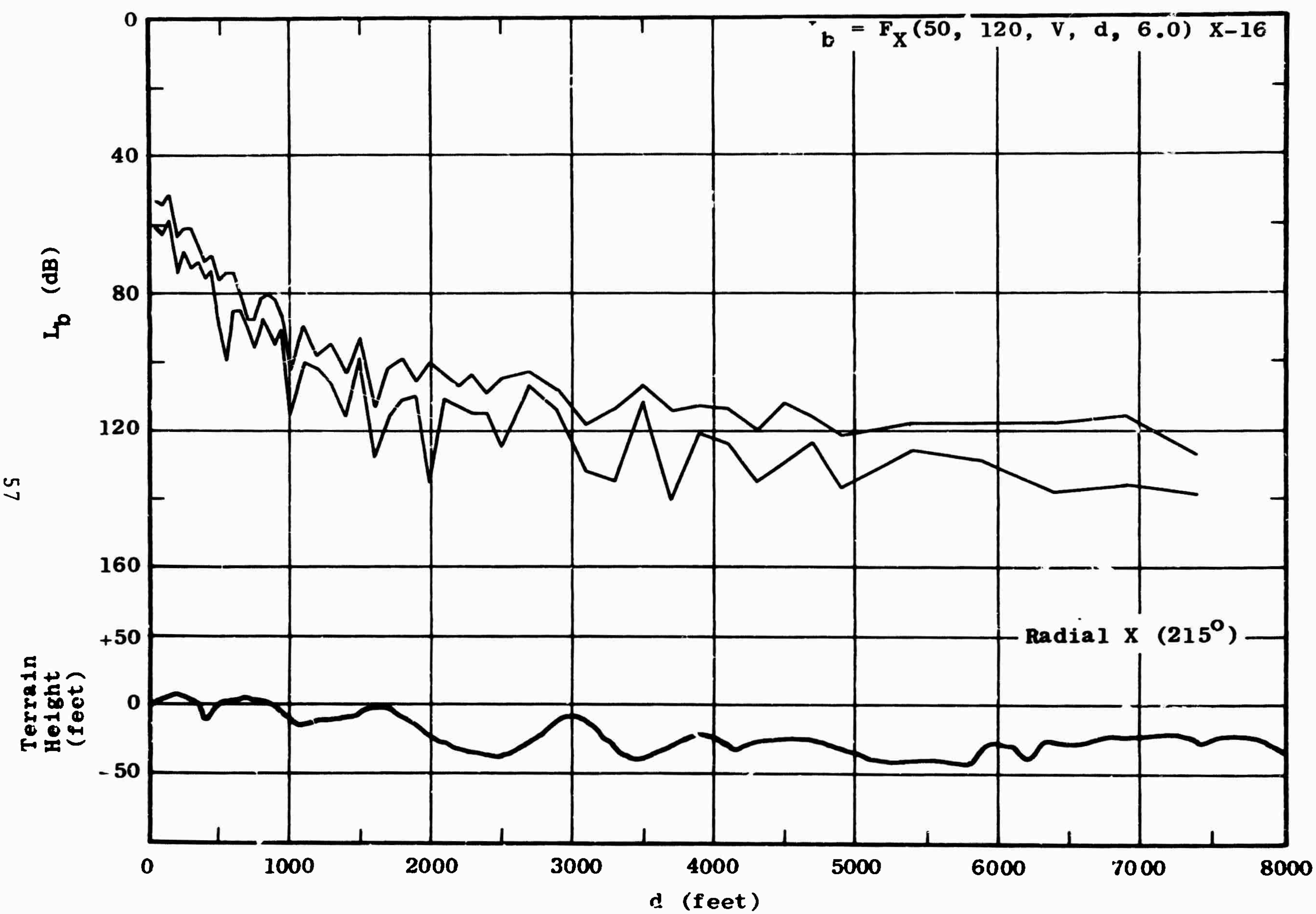

Figure 2.45 Maximum and Minimum Basic Transmission Loss as a Function of Distance

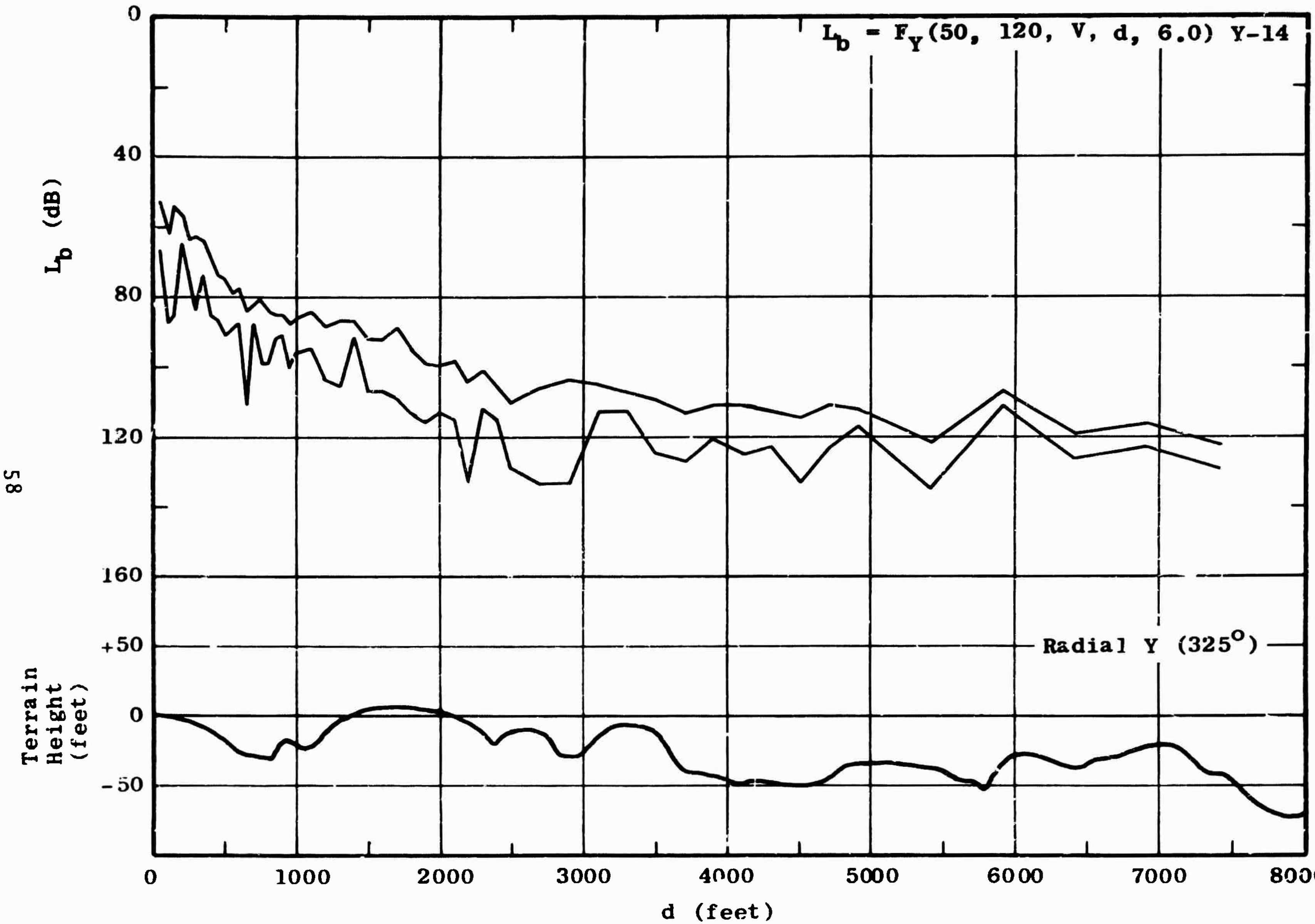

Figure 2.46 Maximum and Minimum Basic Transmission Loss as a Function of Distance

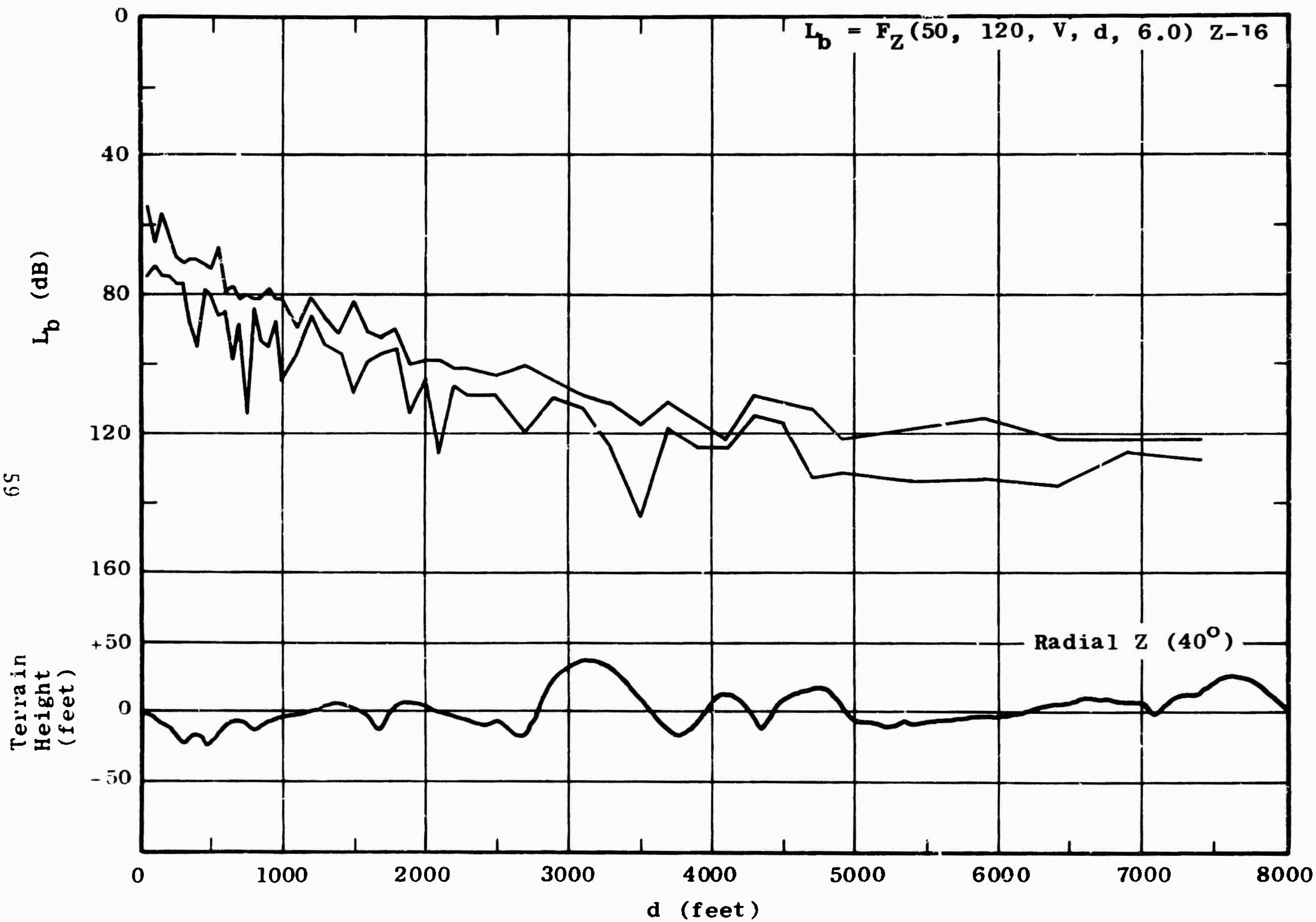

Figure 2.47 Maximum and Minimum Basic Transmission Loss as a Function of Distance

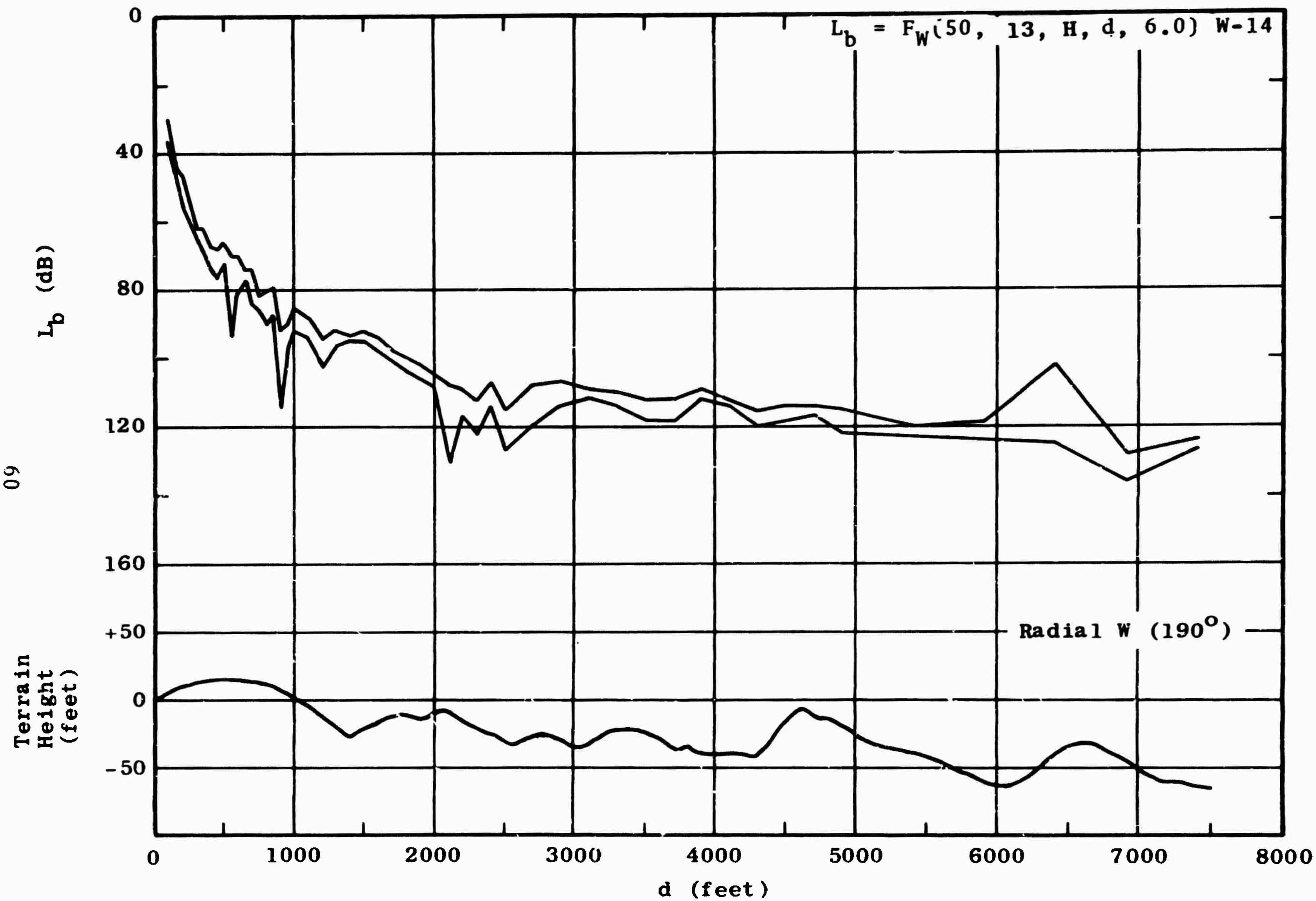

Figure 2.48 Maximum and Minimum Basic Transmission Loss as a Function of Distance

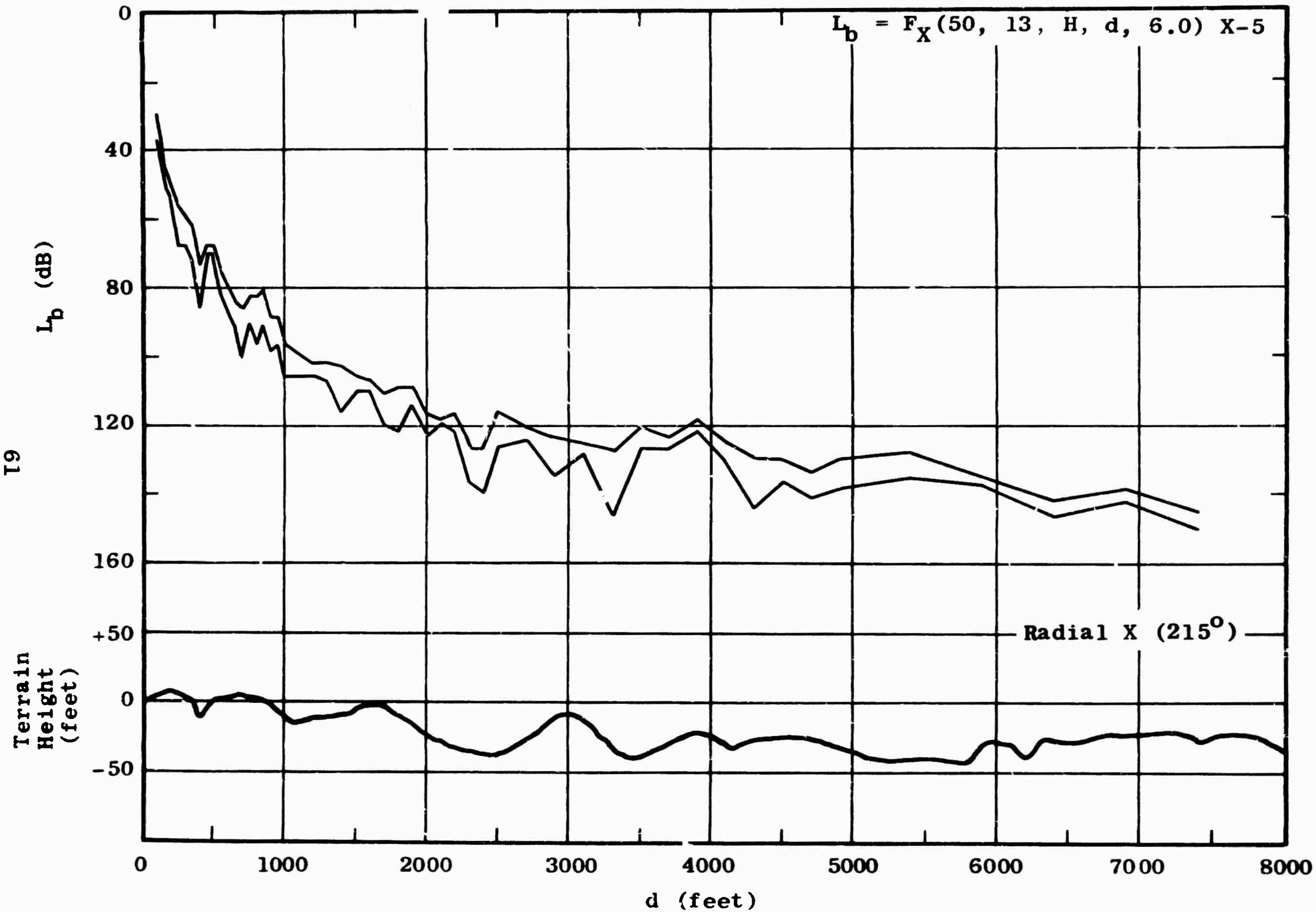

Figure 2.49 Maximum and Minimum Basic Transmission Loss as a Function of Distance

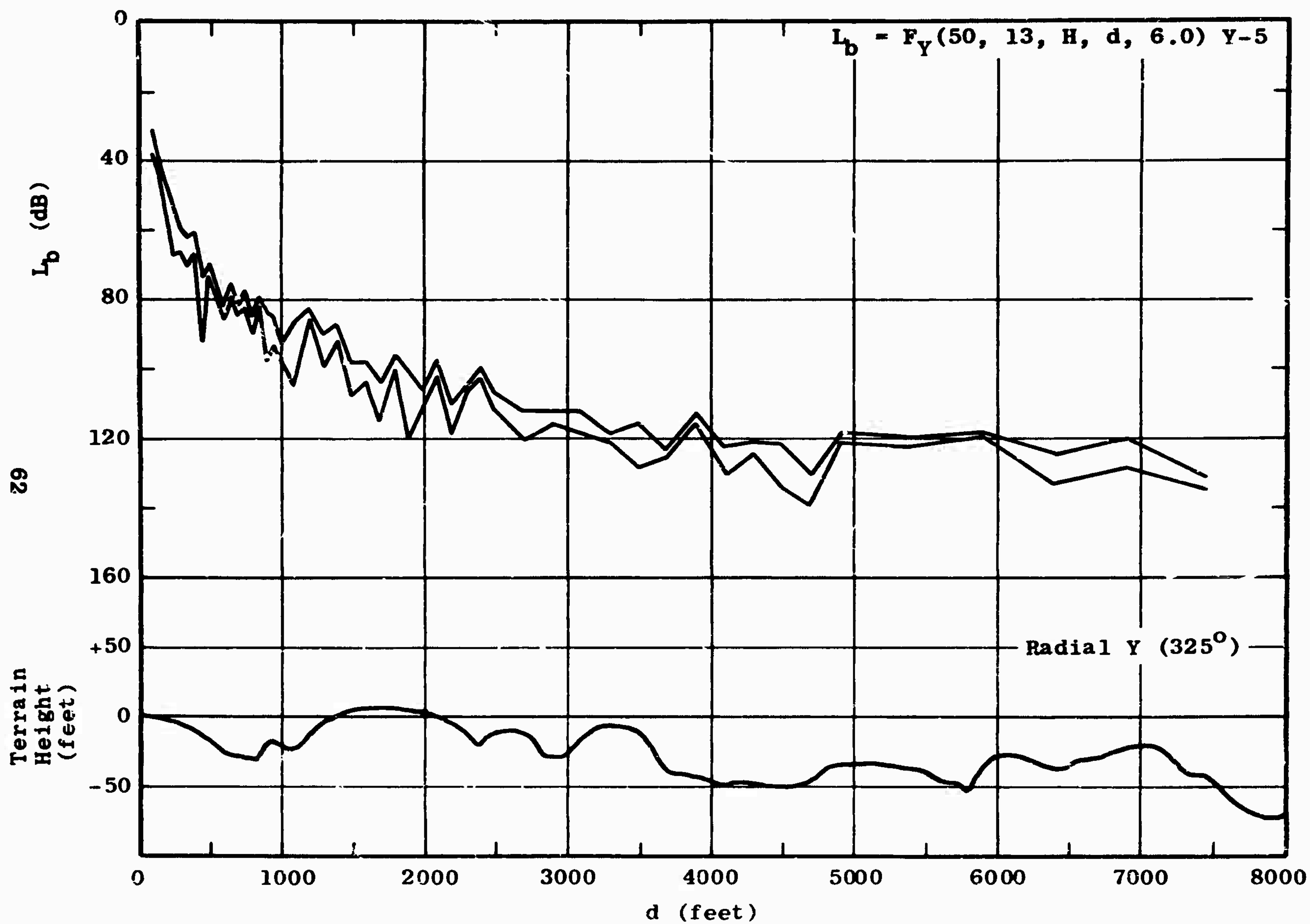

Figure 2.50 Maximum and Minimum Basic Transmission Loss as a Function of Distance

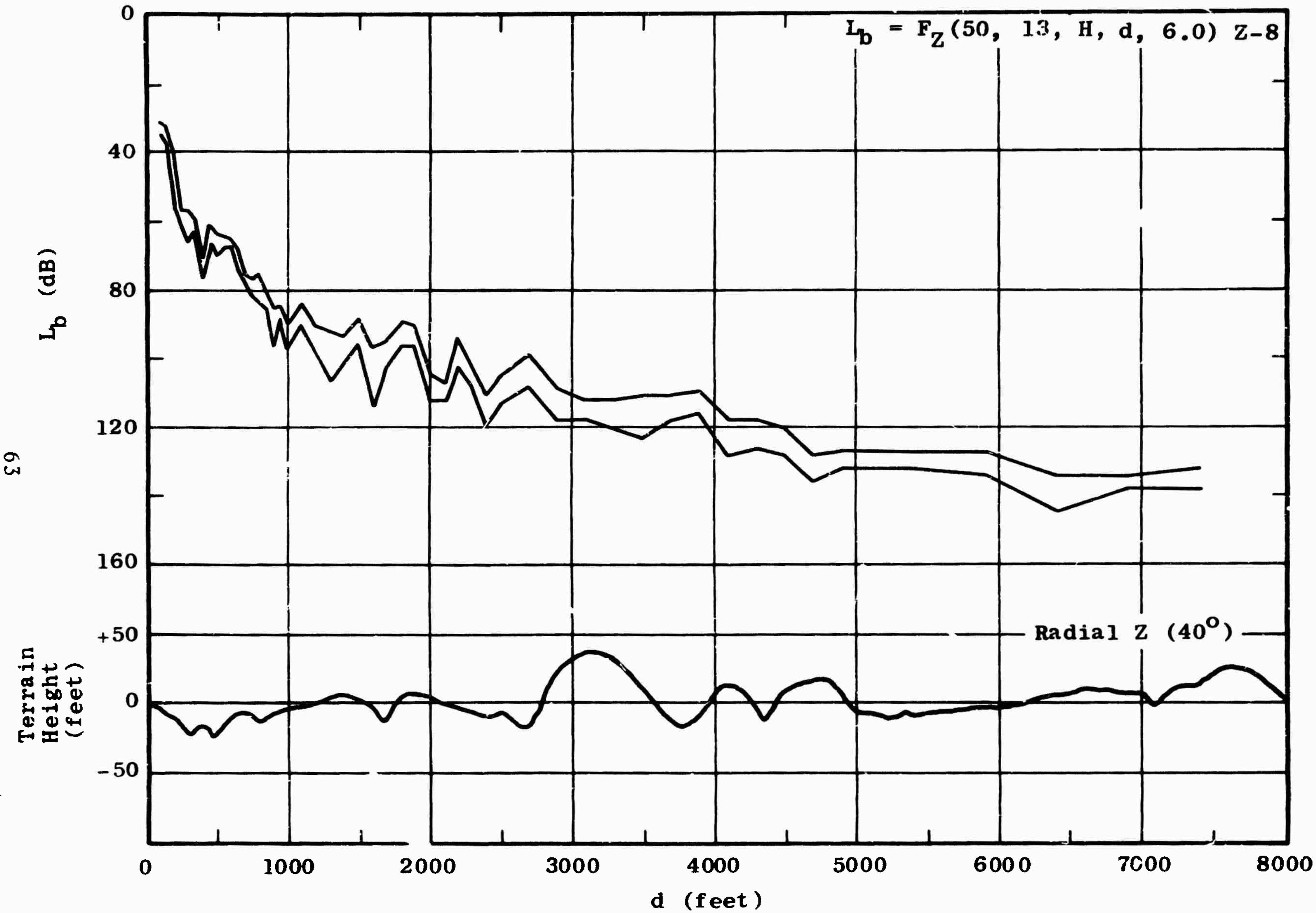

Figure 2.51 Maximum and Minimum Basic Transmission Loss as a Function of Distance

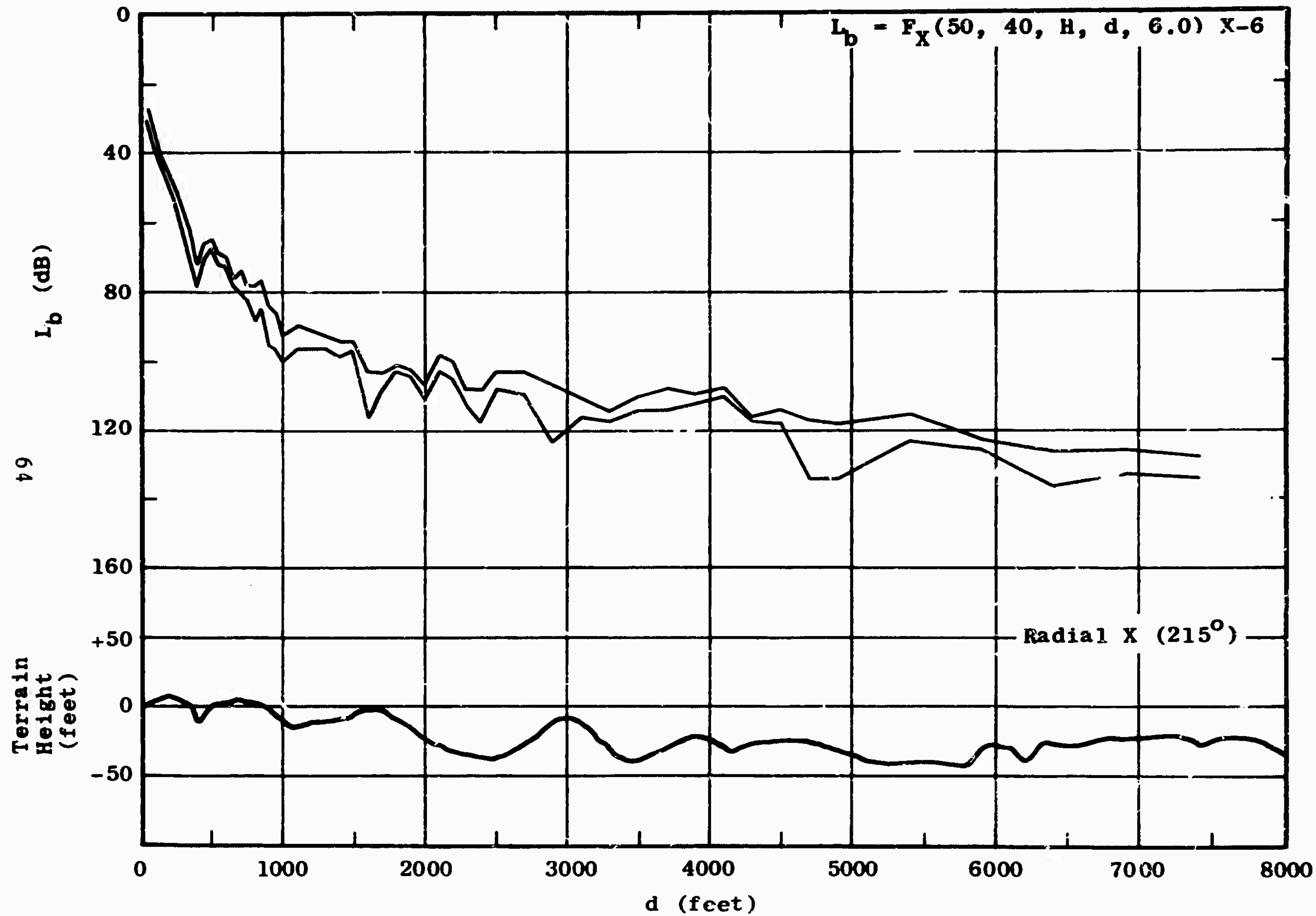

Figure 2.52 Maximum and Minimum Basic Transmission Loss as a Function of Distance

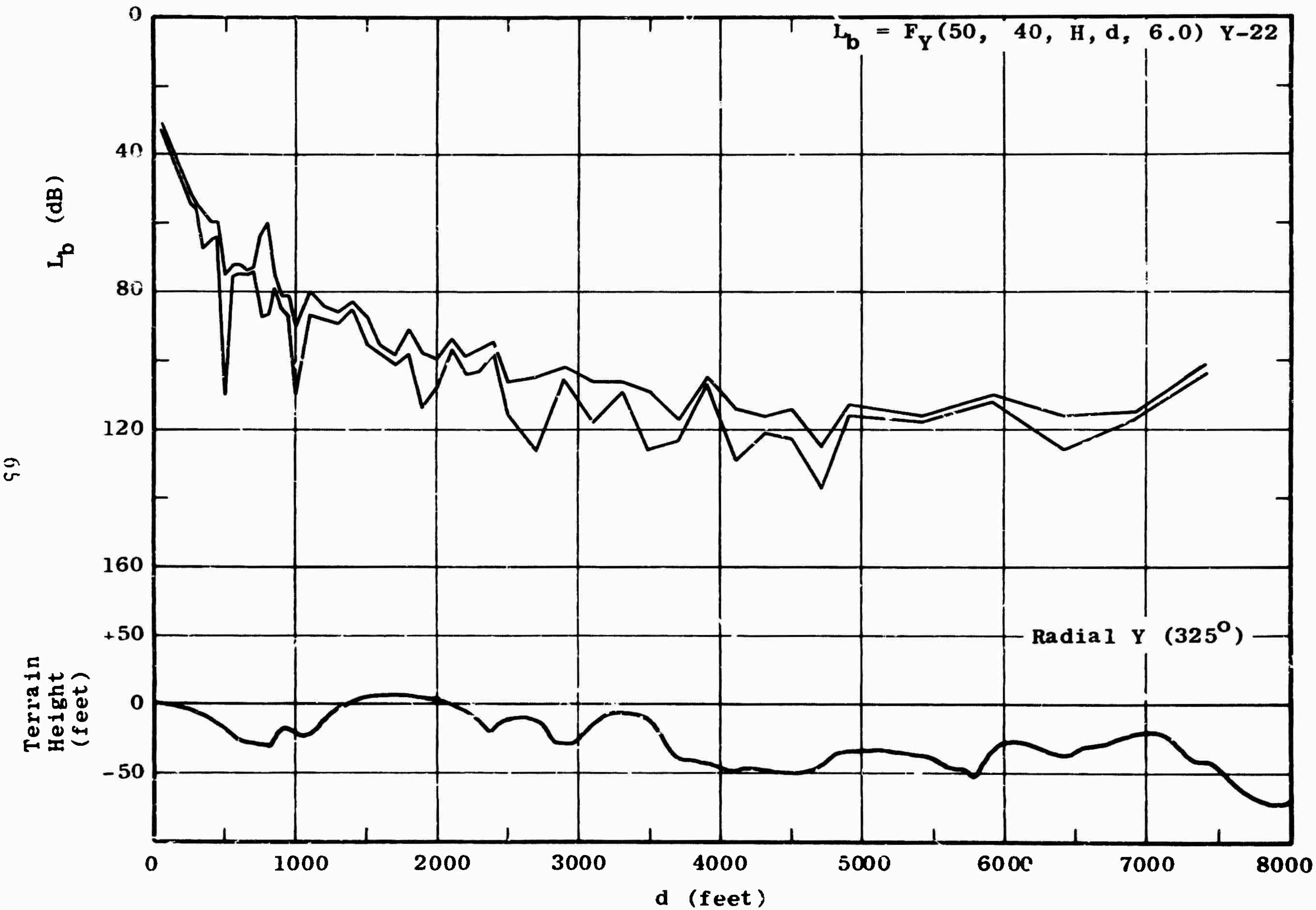

Figure 2.53 Maximum and Minimum Basic Transmission Loss as a Function of Distance

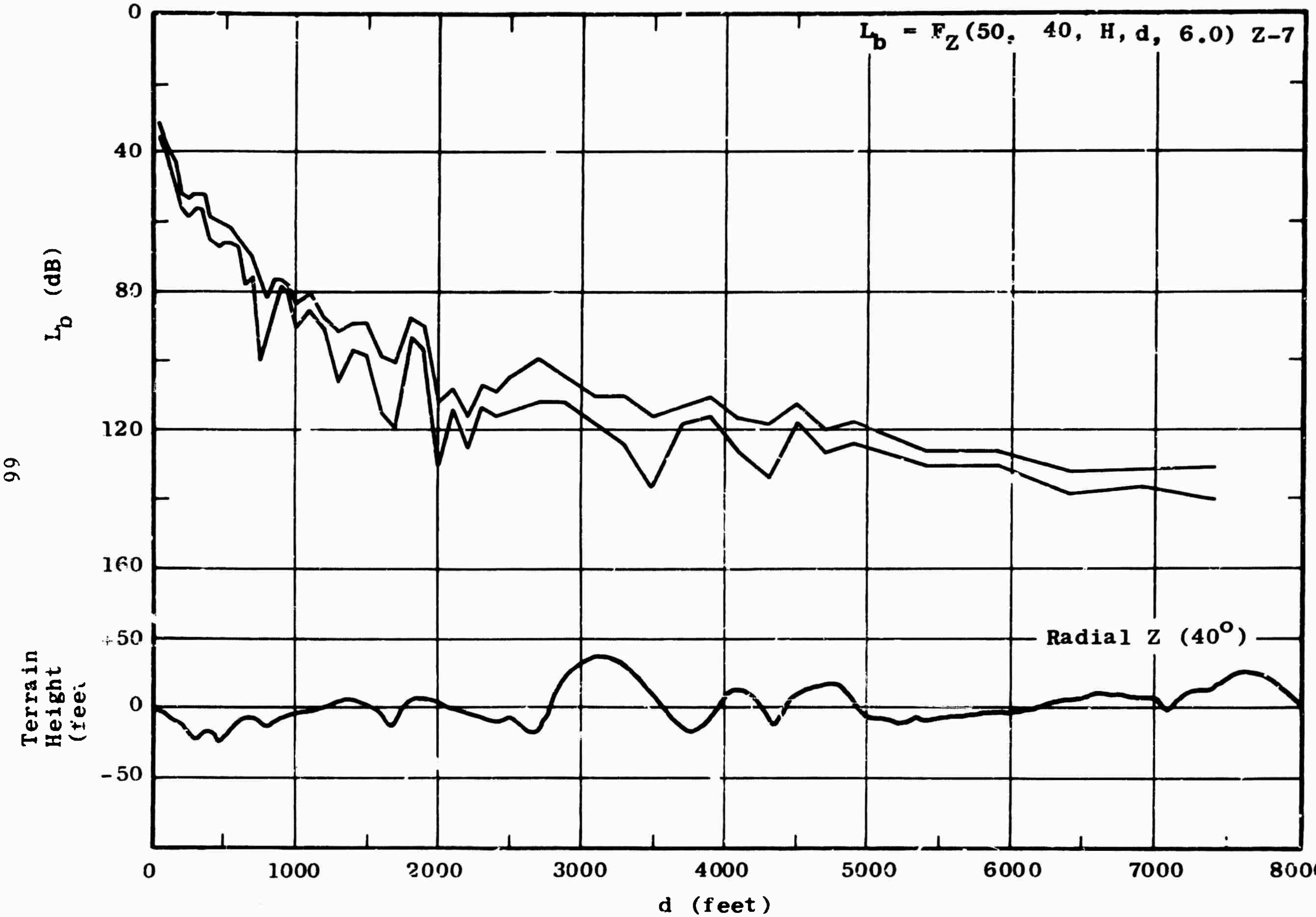

Figure 2.54 Maximum and Minimum Basic Transmission Loss as a Function of Distance

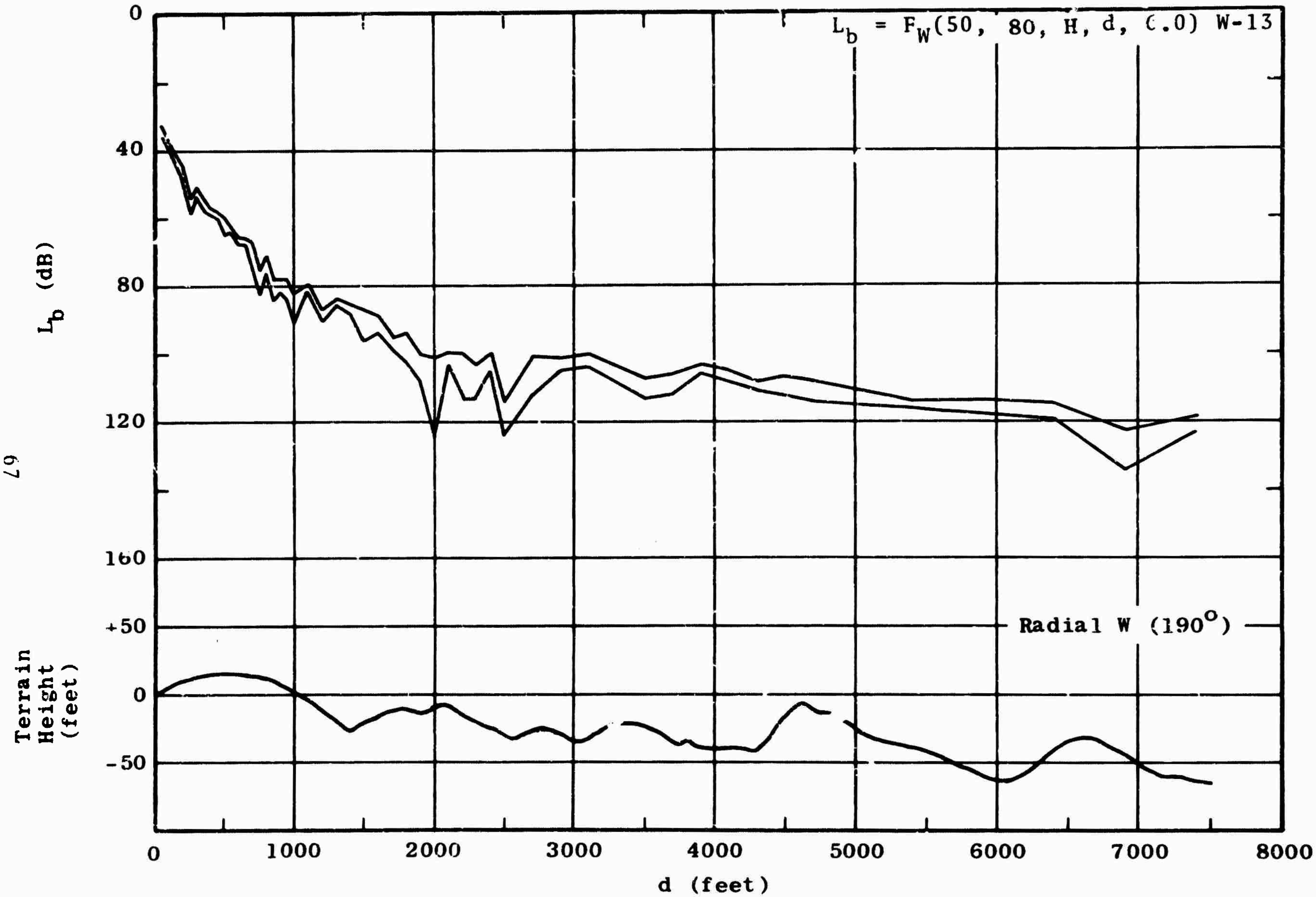

Figure 2.55 Maximum and Minimum Basic Transmission Loss as a Function of Distance

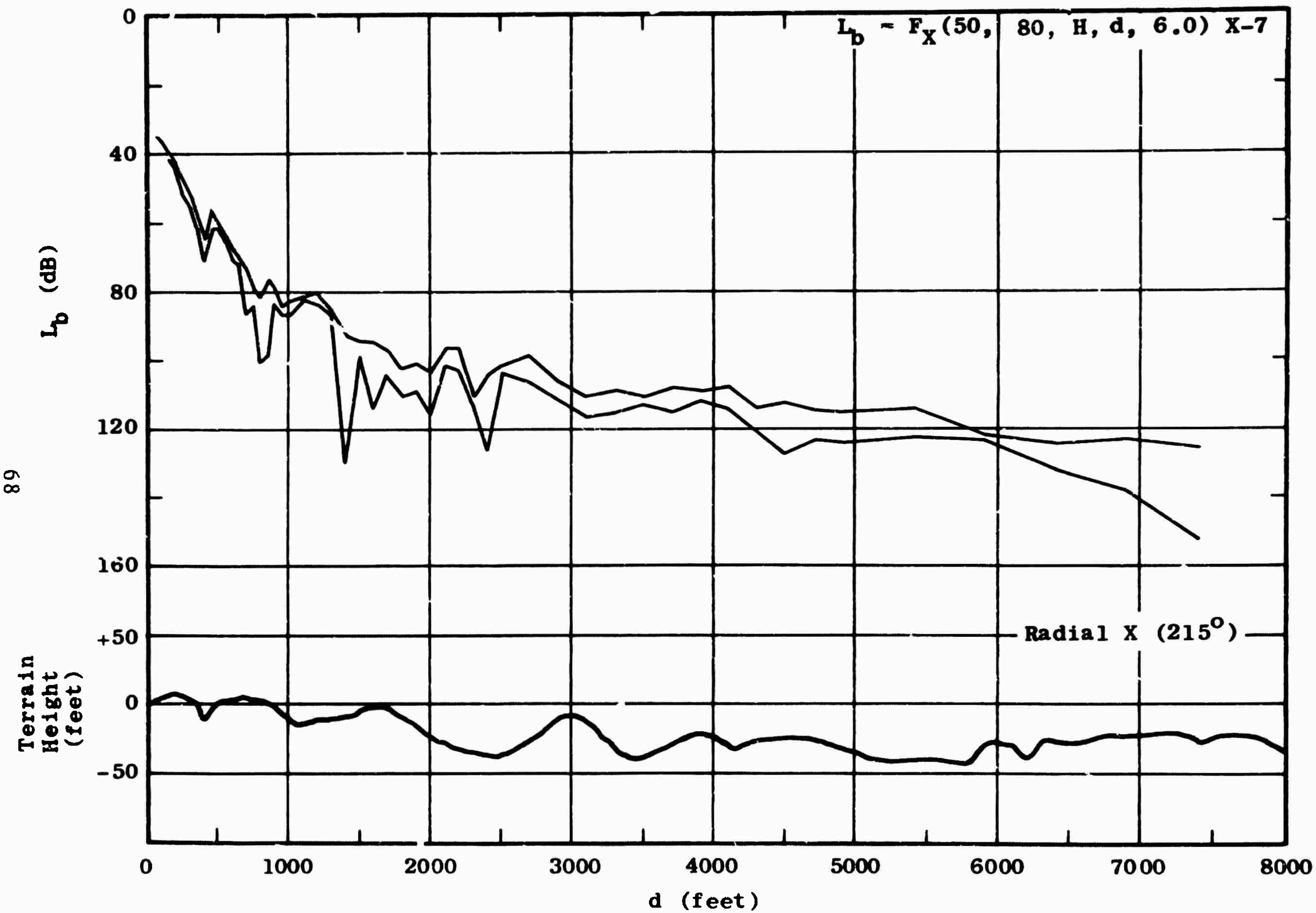

Figure 2.56 Maximum and Minimum Basic Transmission Loss as a Function of Distance

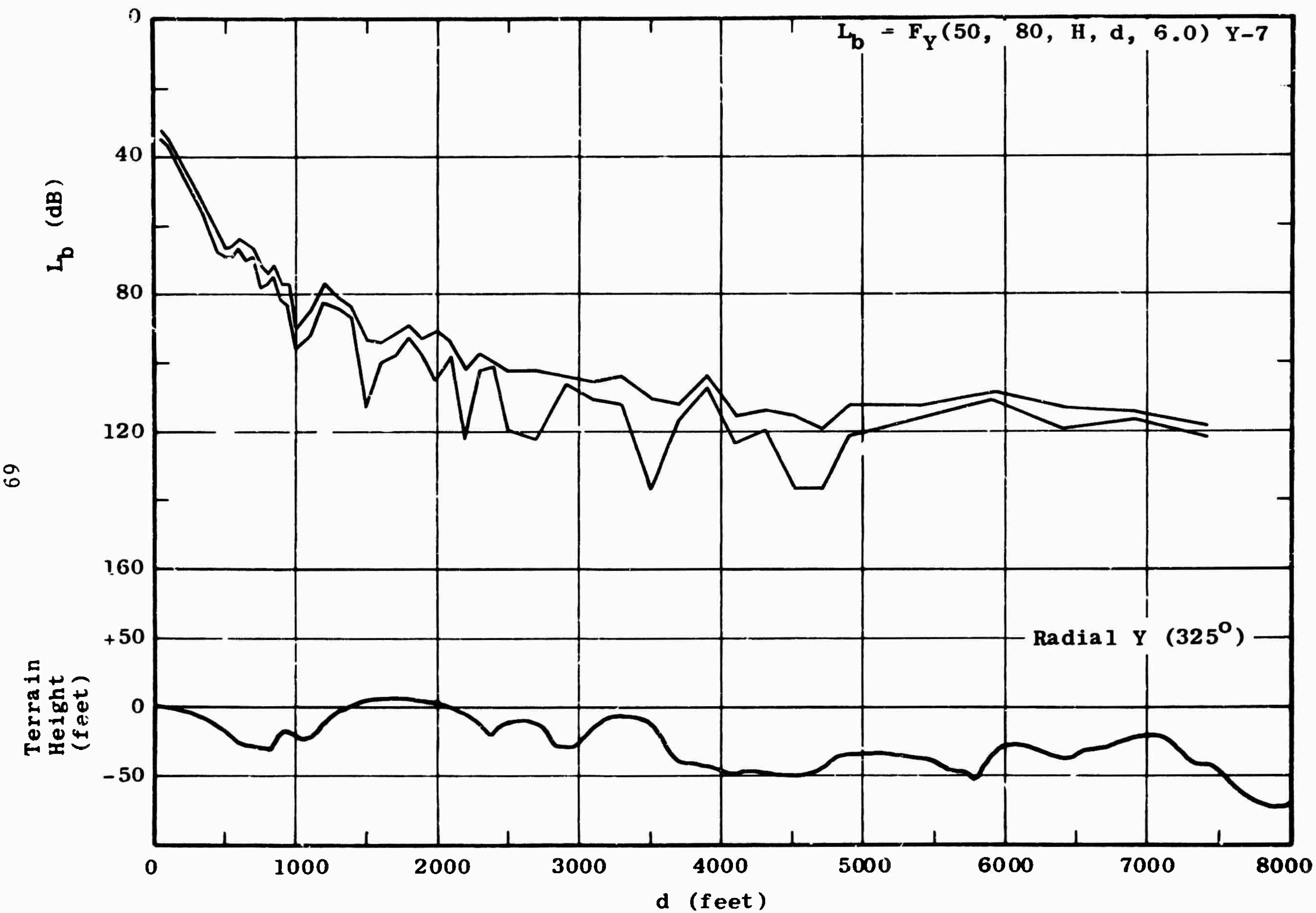

Figure 2.57 Maximum and Minimum Basic Transmission Loss as a Function of Distance

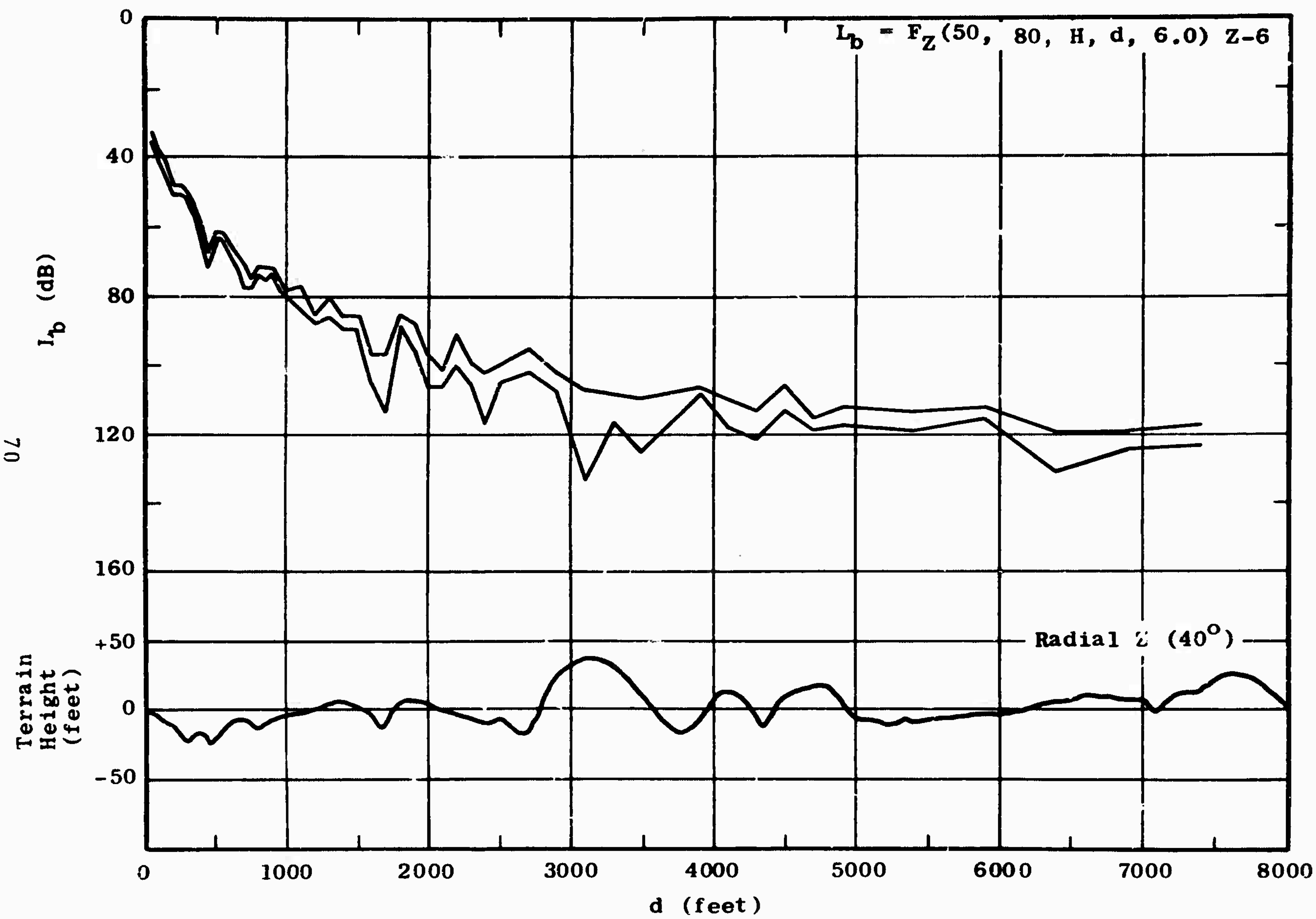

Figure 2.58 Maximum and Minimum Basic Transmission Loss as a Function of Distance

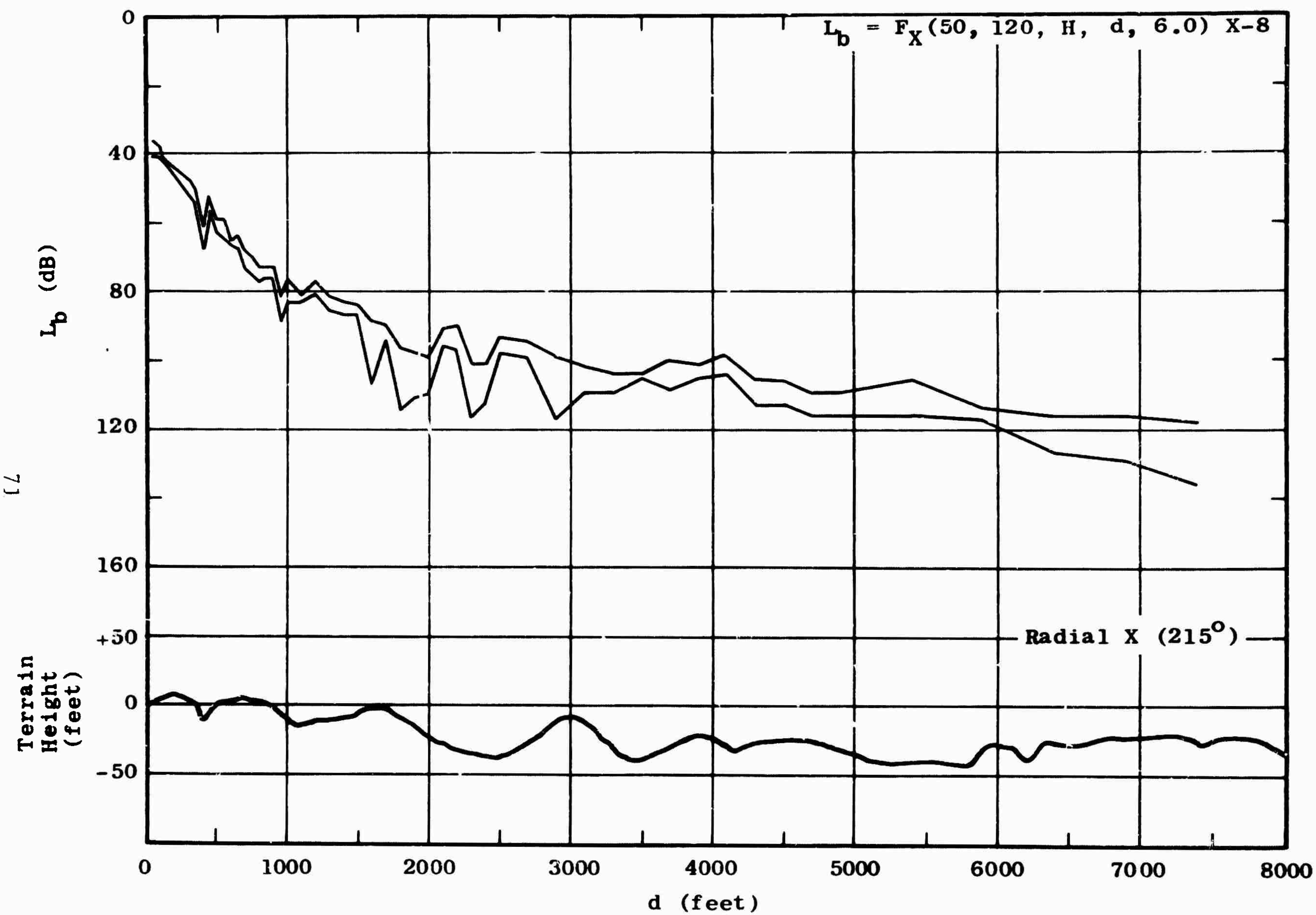

Figure 2.59 Maximum and Minimum Basic Transmission Loss as a Function of Distance

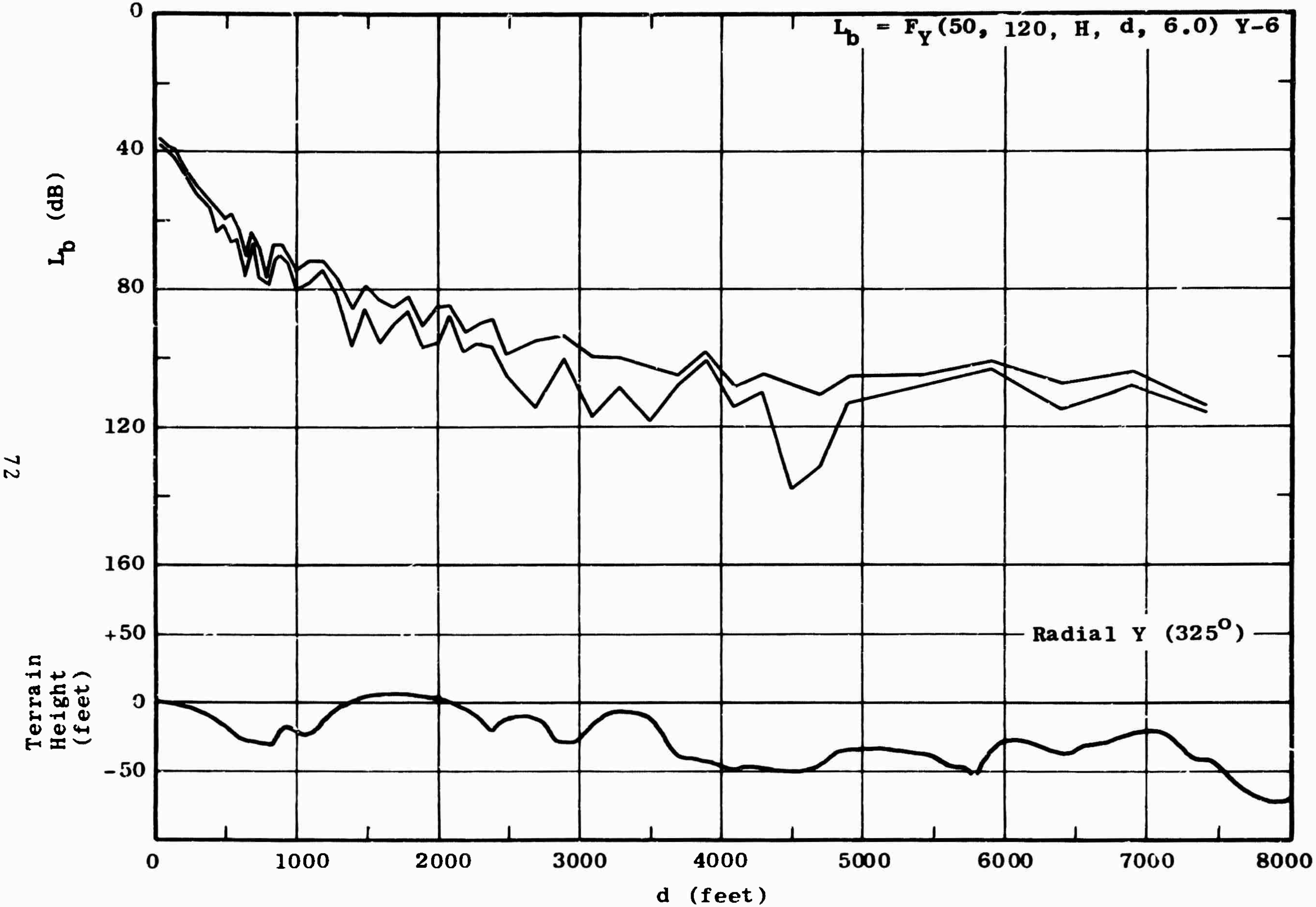

Figure 2.60 Maximum and Minimum Basic Transmission Loss as a Function of Distance

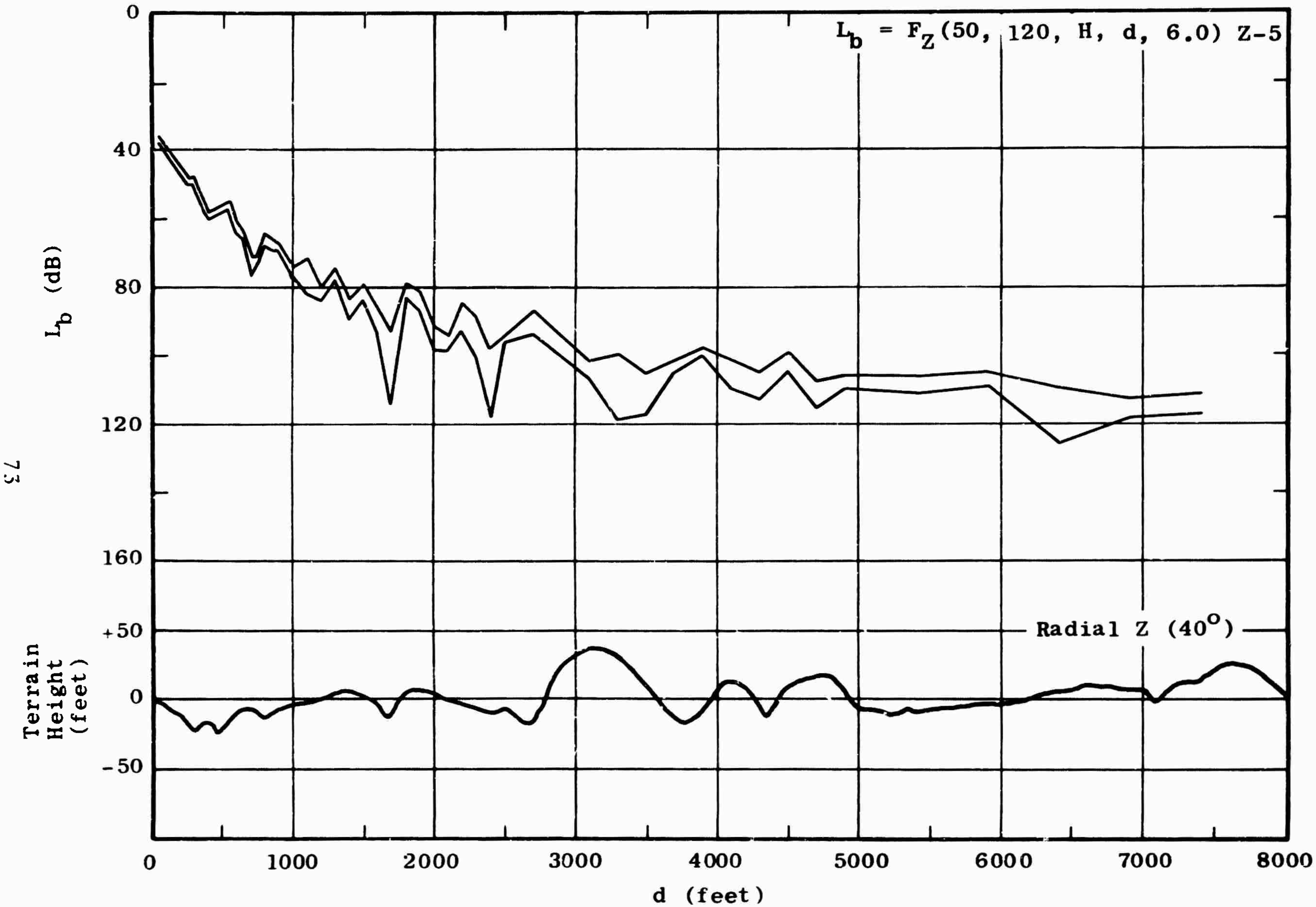

Figure 2.61 Maximum and Minimum Basic Transmission Loss as a Function of Distance

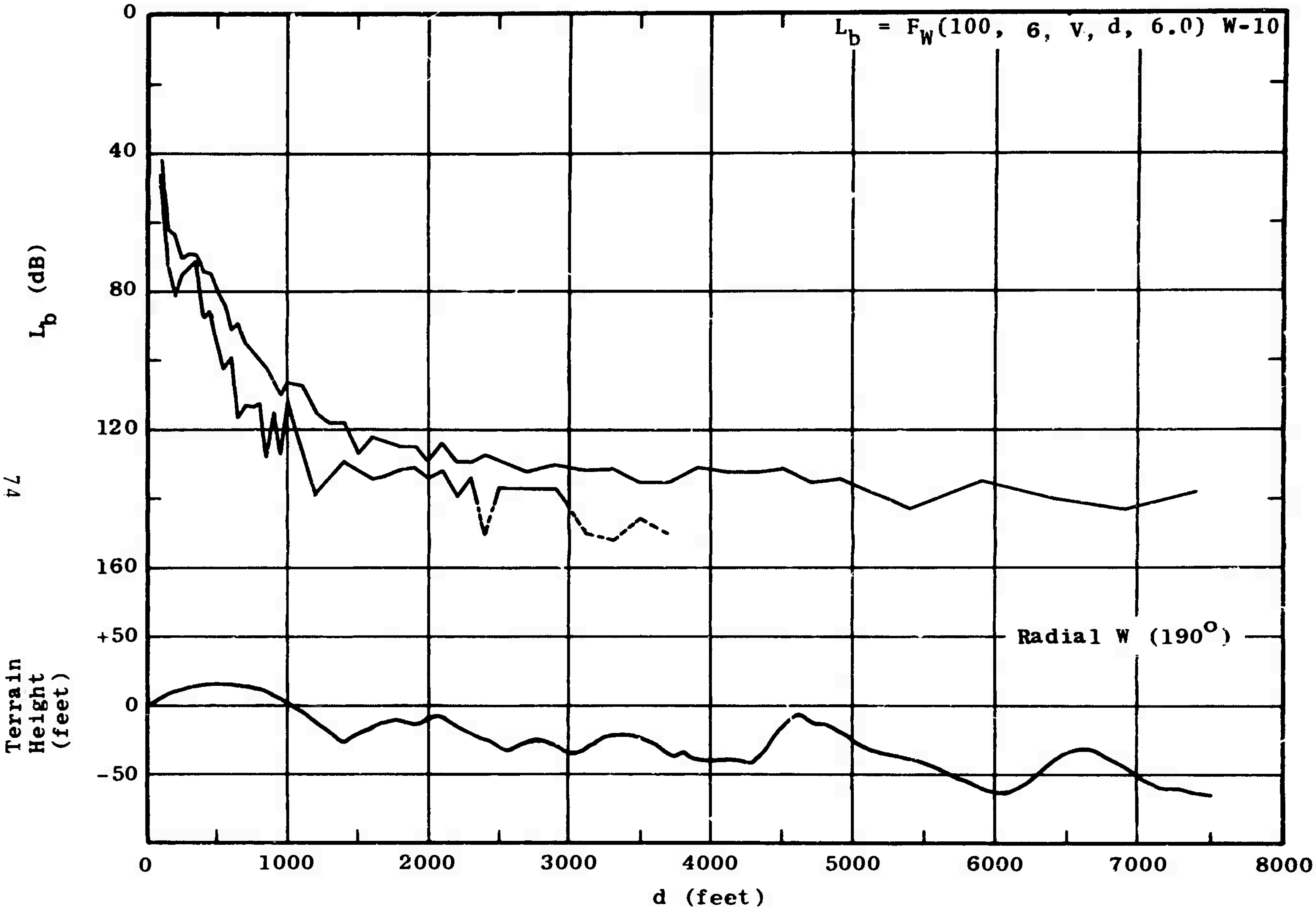

Figure 2.62 Maximum and Minimum Basic Transmission Loss as a Function of Distance

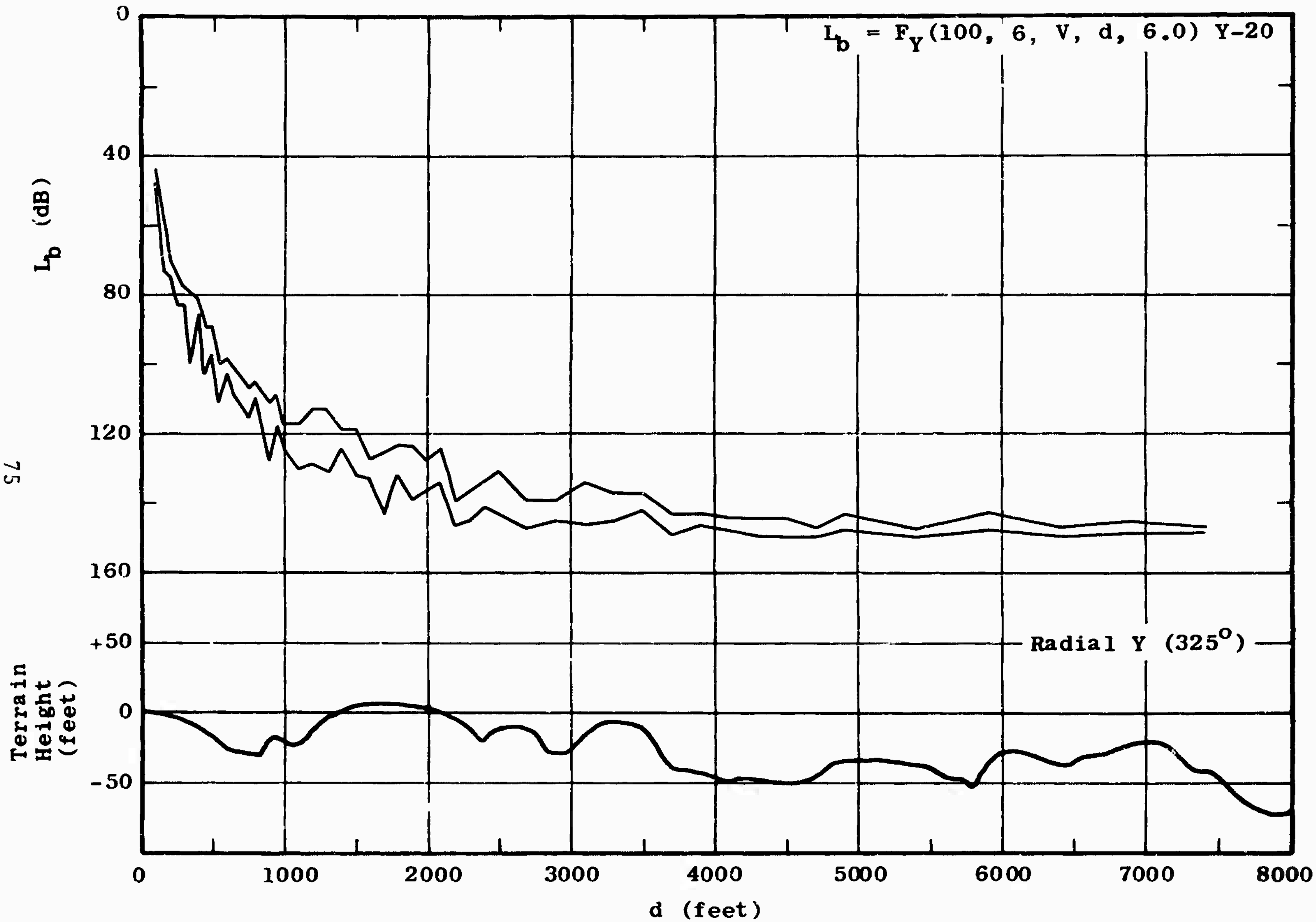

Figure 2.63 Maximum and Minimum Basic Transmission Loss as a Function of Distance

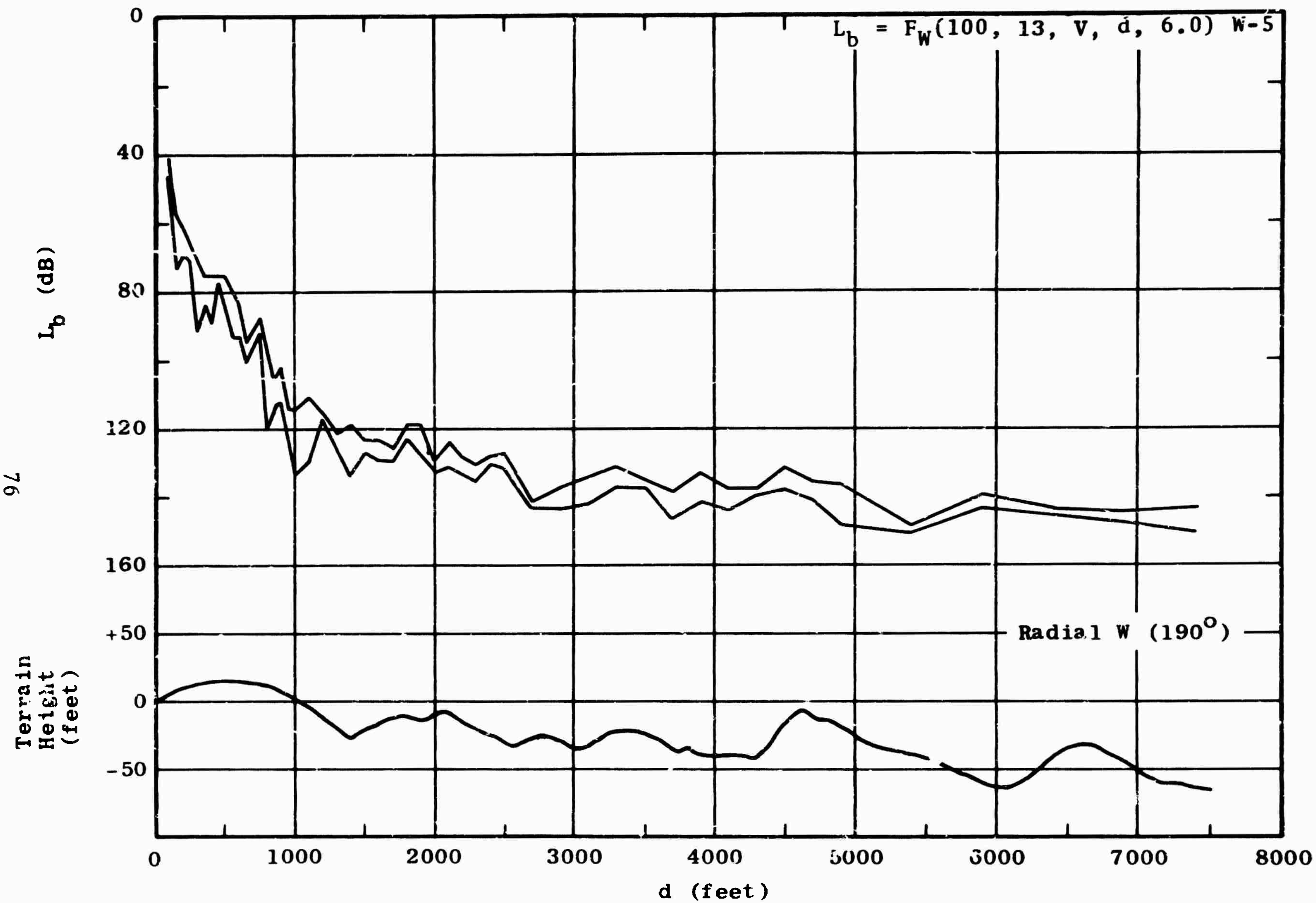

Figure 2.64 Maximum and Minimum Basic Transmission Loss as a Function of Distance

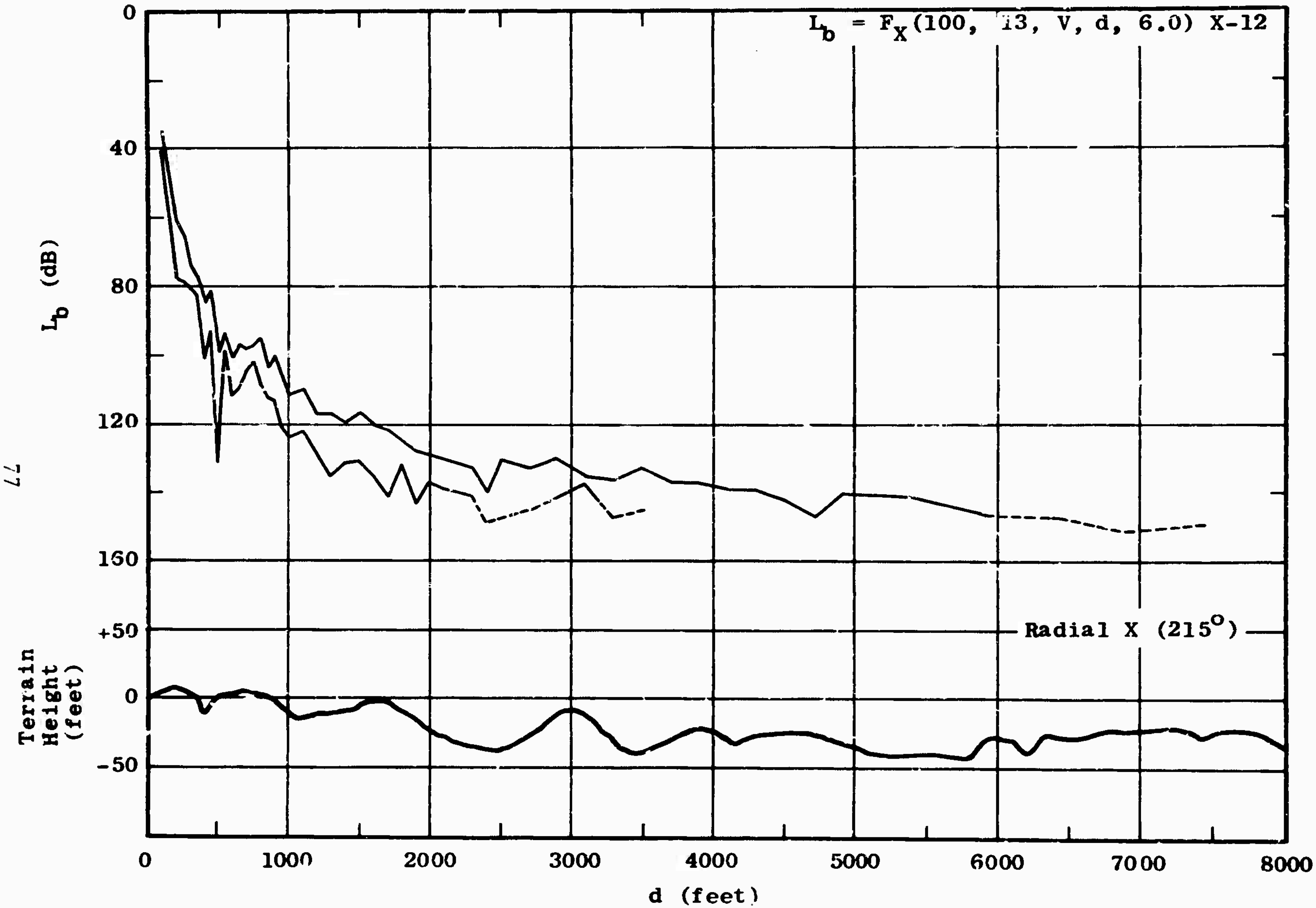

Figure 2.65 Maximum and Minimum Basic Transmission Loss as a Function of Distance

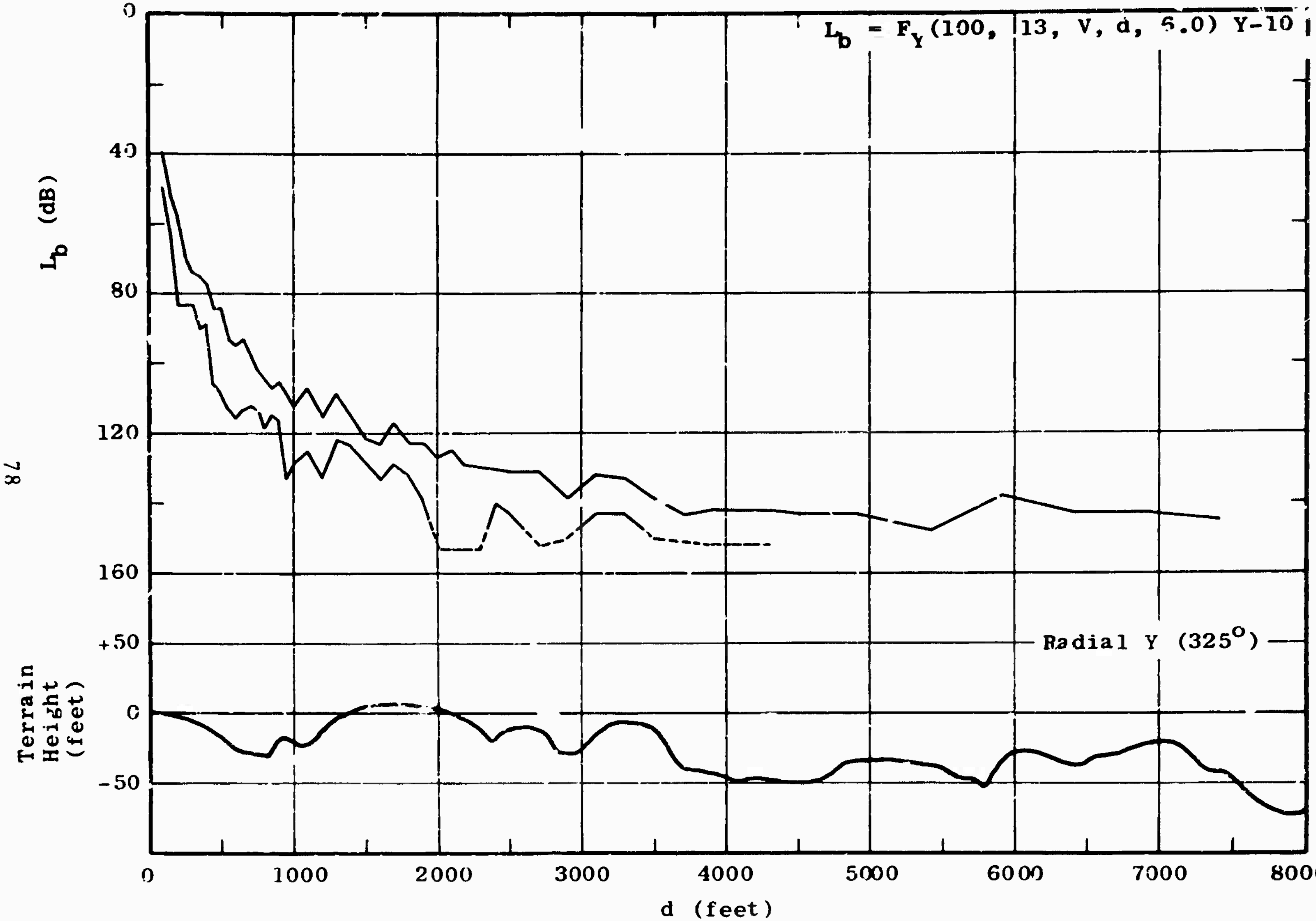

Figure 2.66 Maximum and Minimum Basic Transmission Loss as a Function of Distance

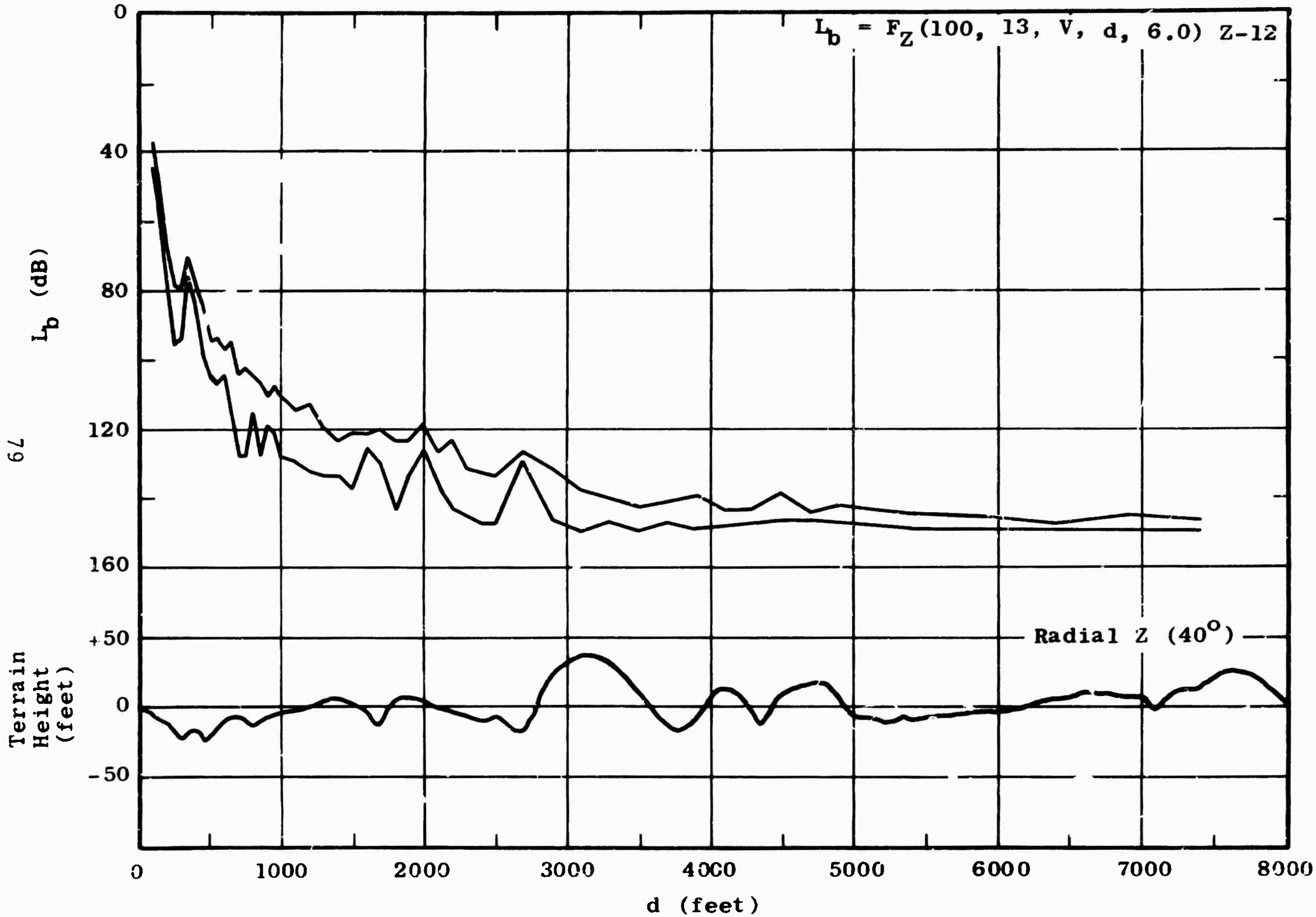

Figure 2.67 Maximum and Minimum Basic Transmission Loss as a Function of Distance

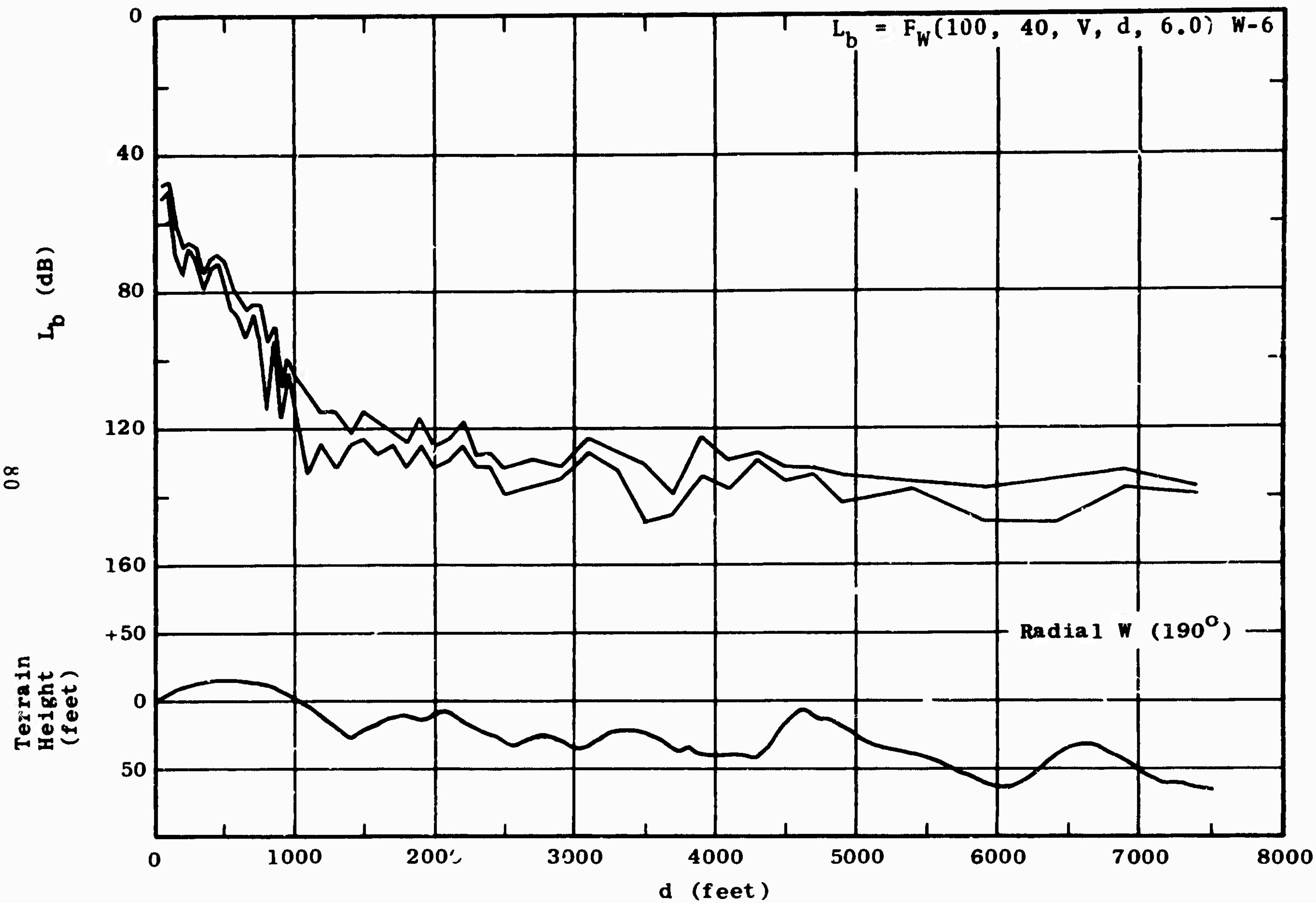

Figure 2.68 Maximum and Minimum Basic Transmission Loss as a Function of Distance

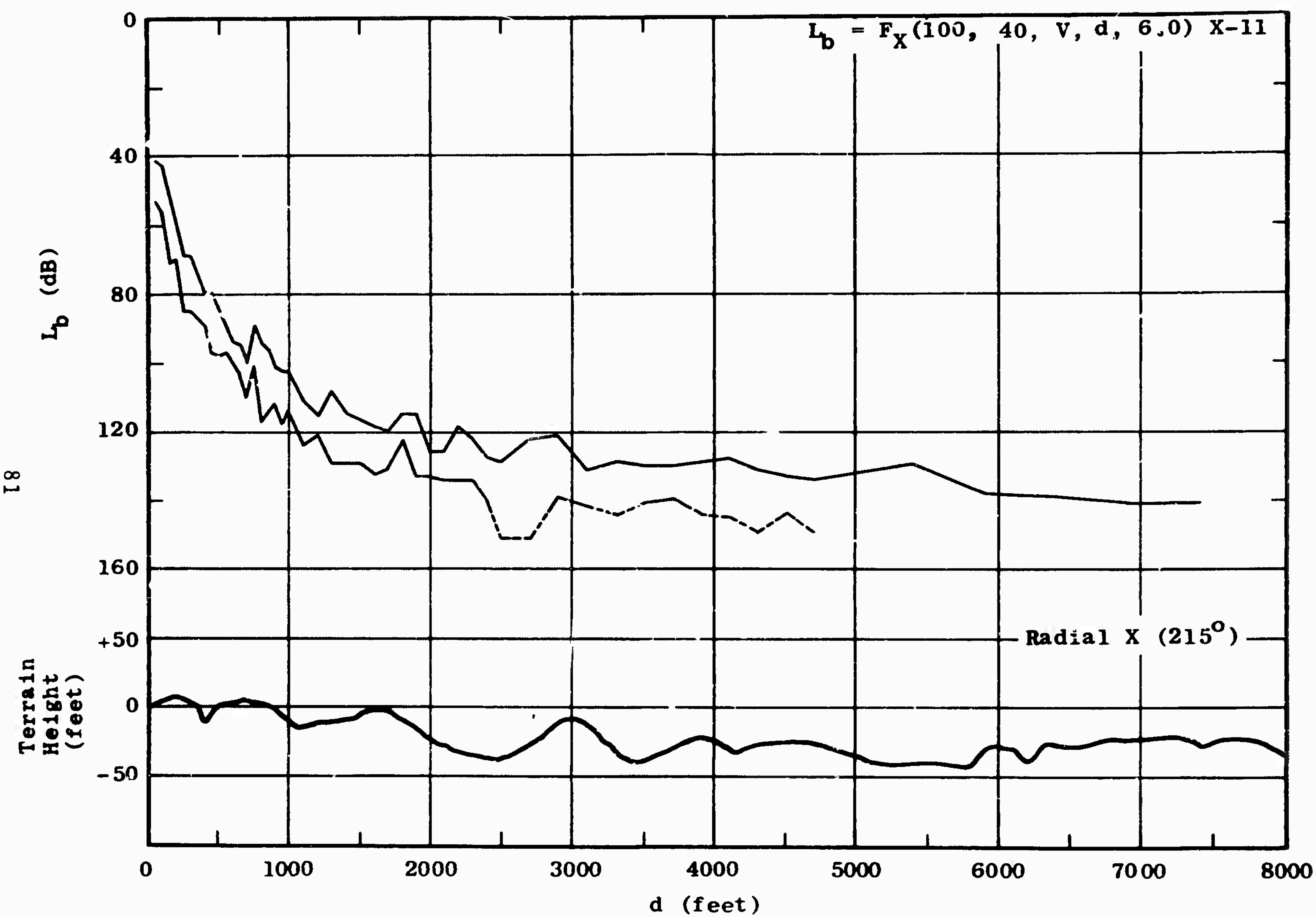

Figure 2.69 Maximum and Minimum Basic Transmission Loss as a Function of Distance

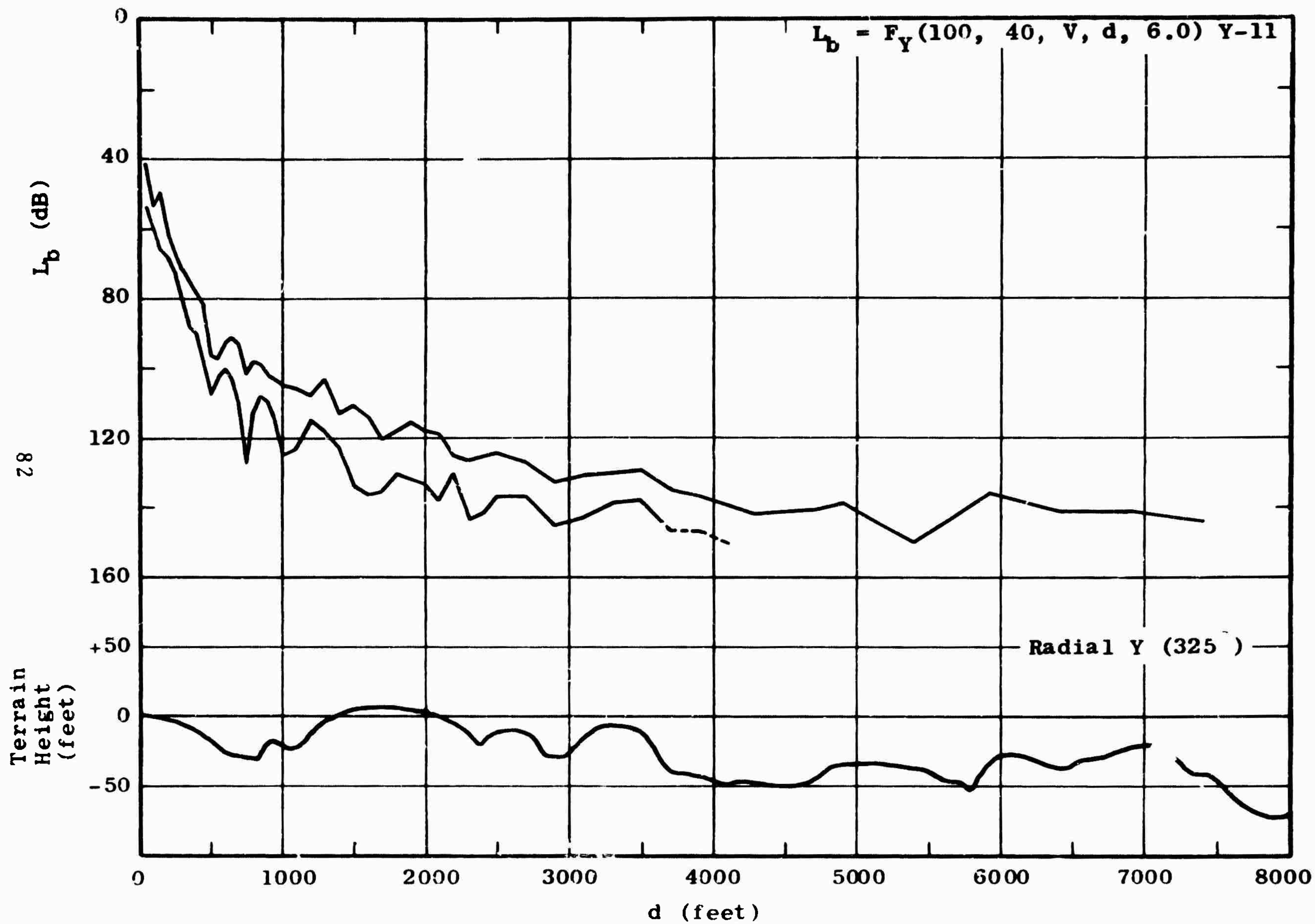

Figure 2.70 Maximum and Minimum Basic Transmission Loss as a Function of Distance

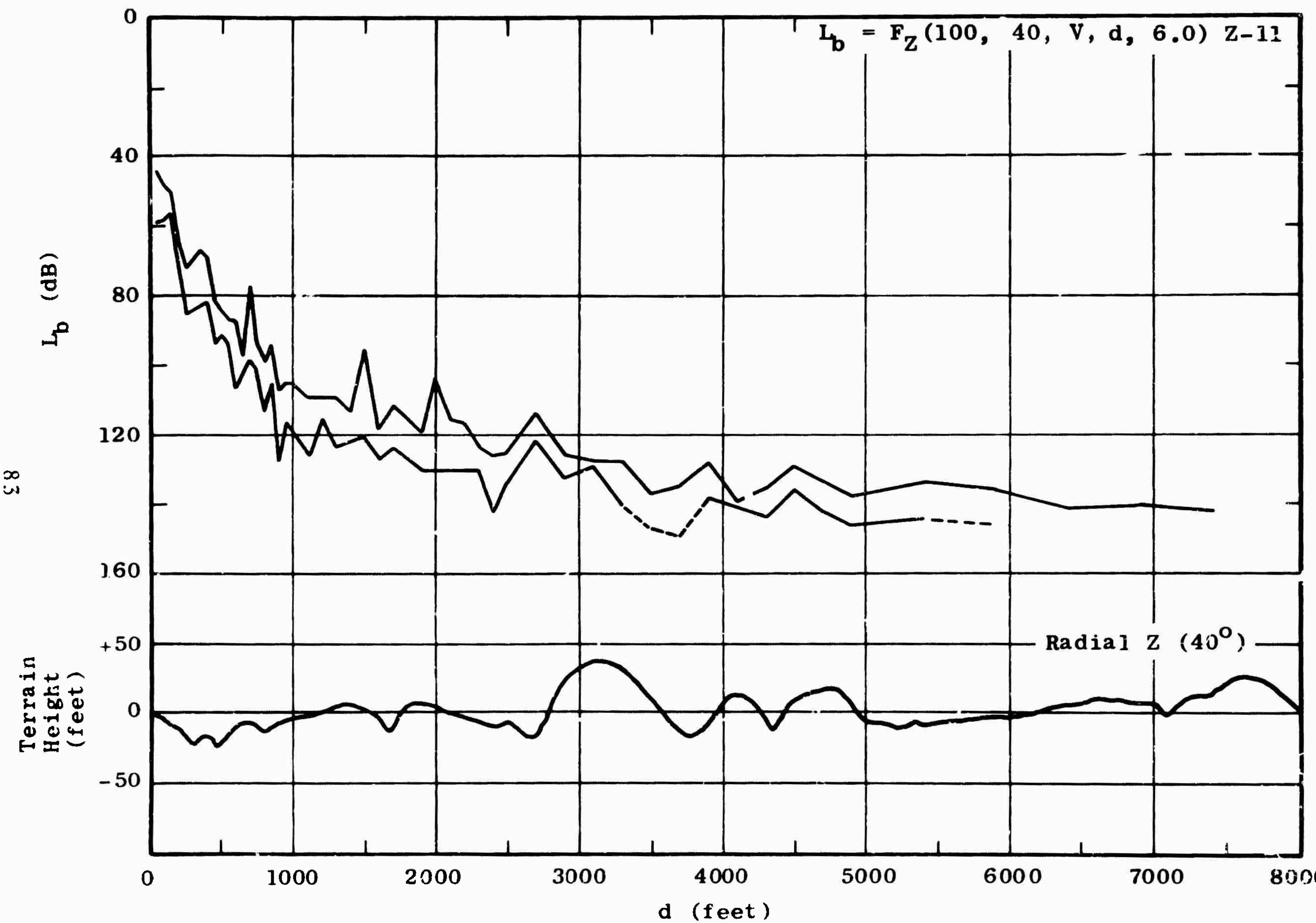

Figure 2.71 Maximum and Minimum Basic Transmission Loss as a Function of Distance

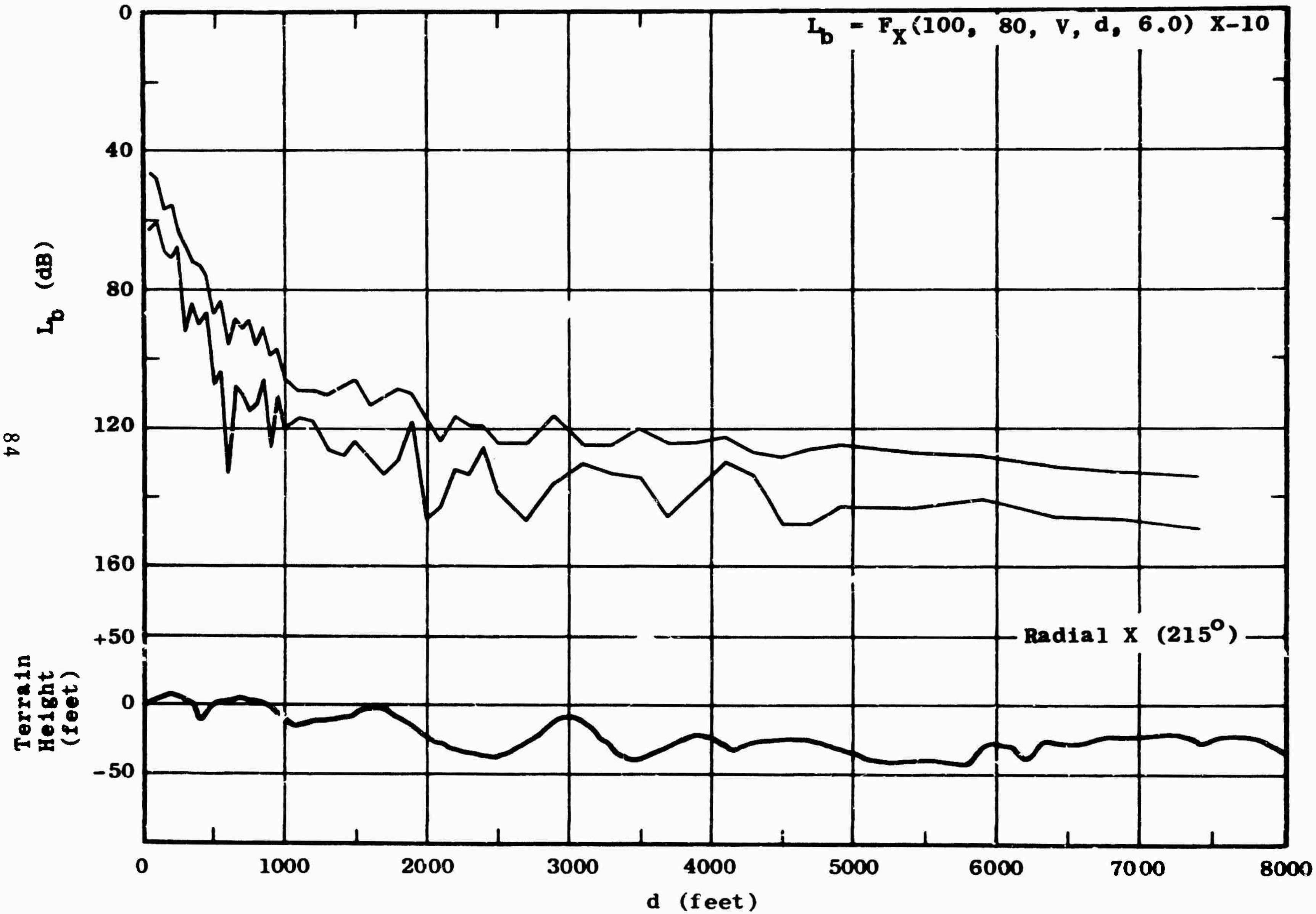

Figure 2.72 Maximum and Minimum Basic Transmission Loss as a Function of Distance

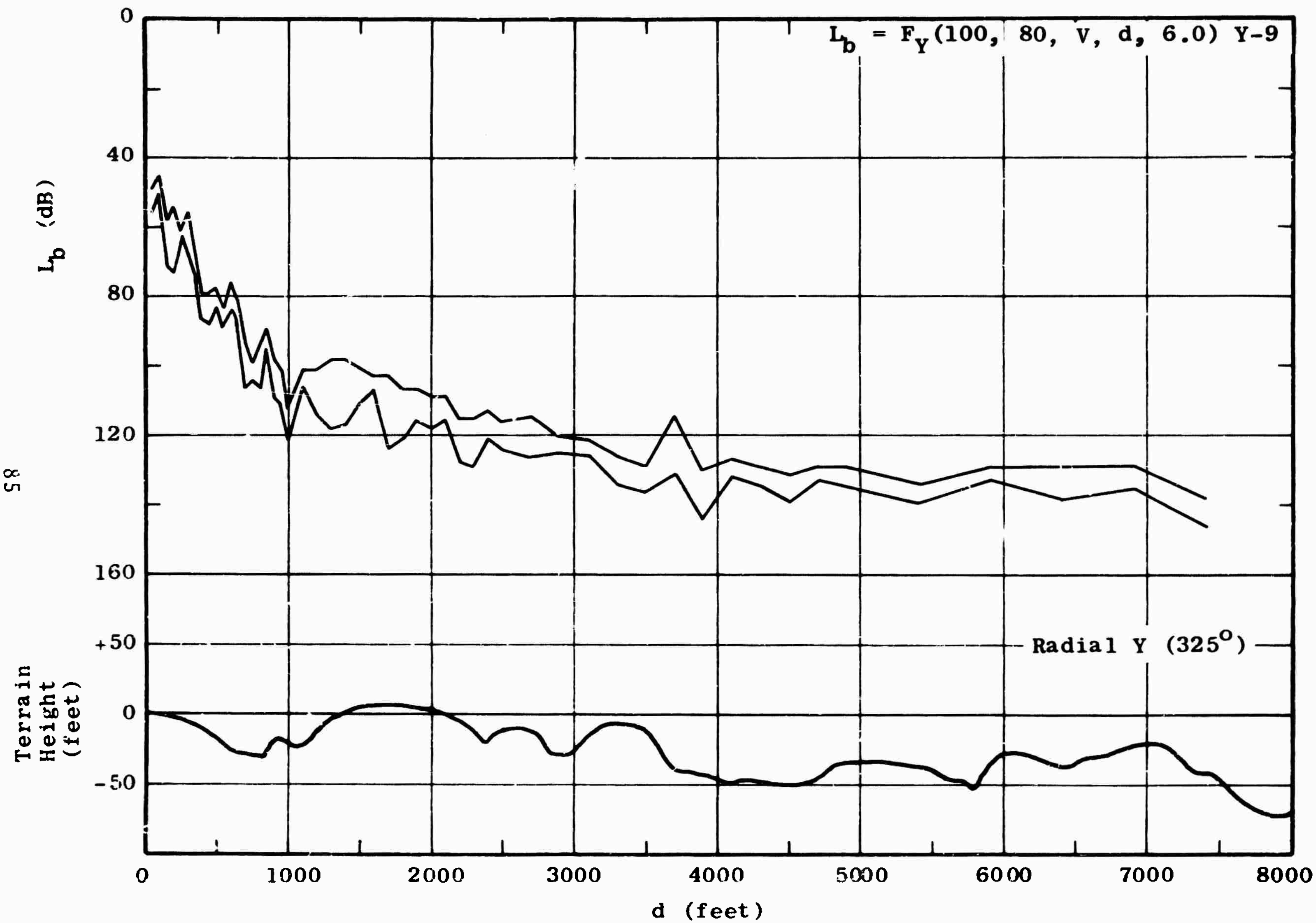

Figure 2.73 Maximum and Minimum Basic Transmission Loss as a Function of Distance

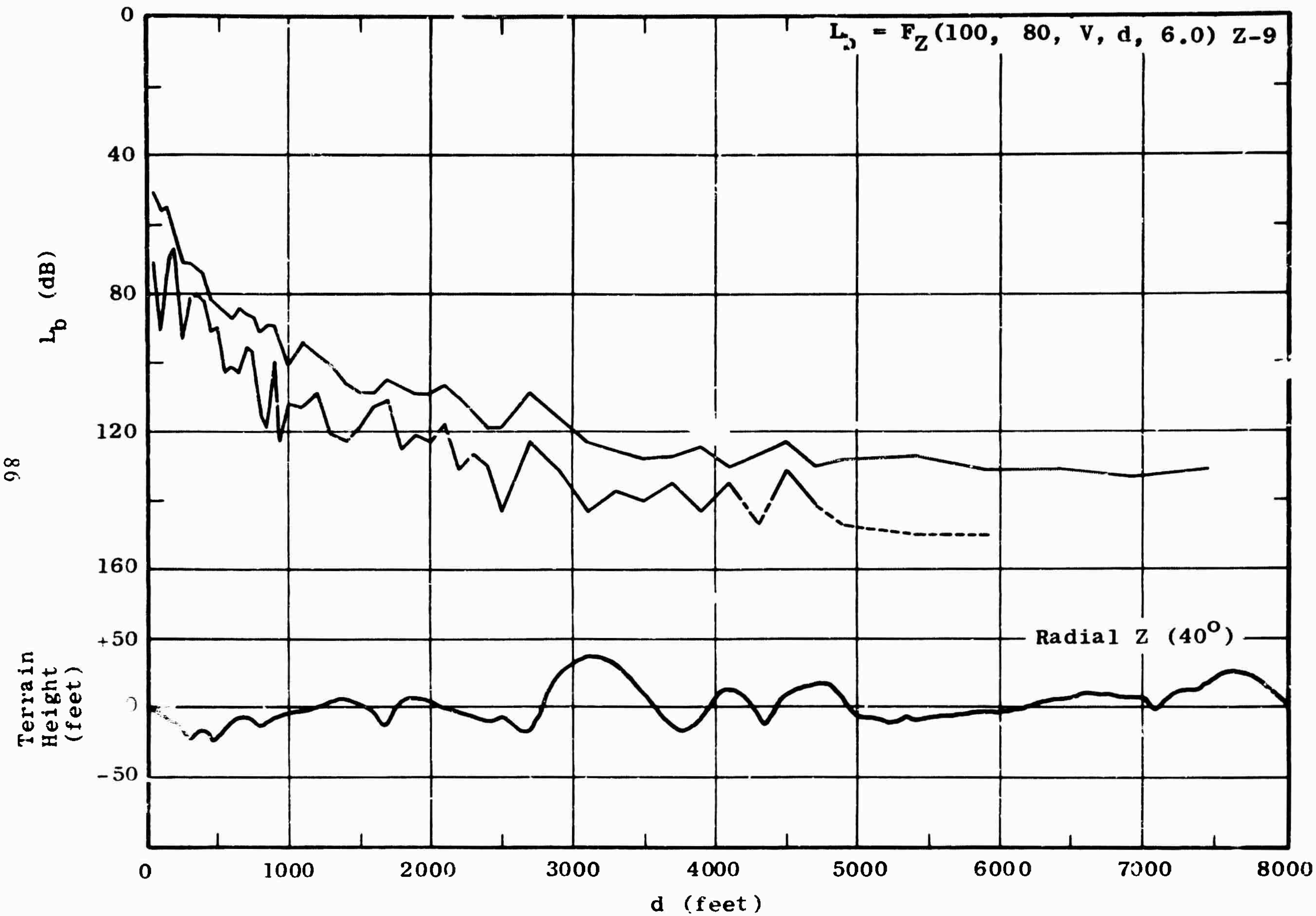

Figure 2.74 Maximum and Minimum Basic Transmission Loss as a Function of Distance

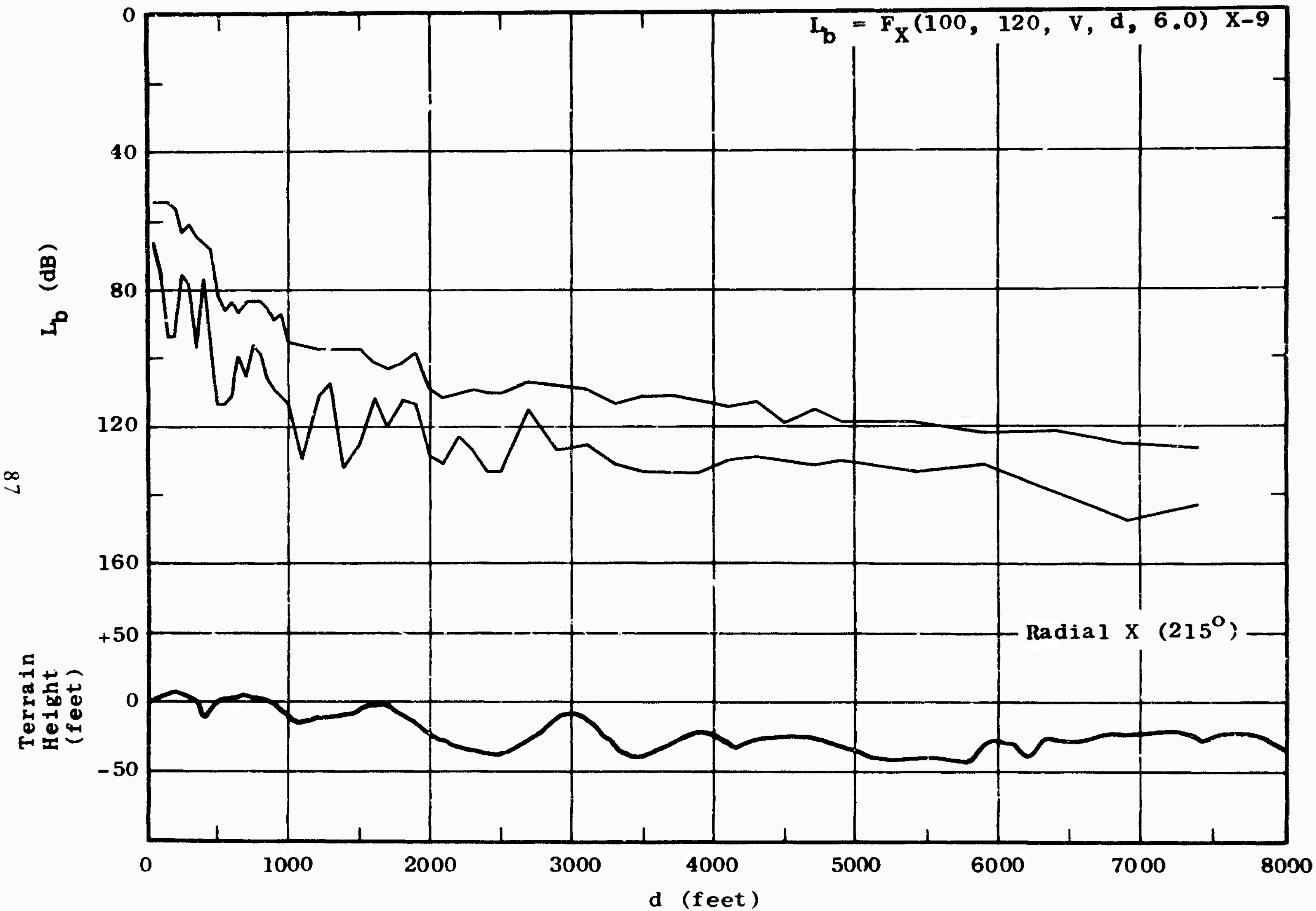

Figure 2.75 Maximum and Minimum Basic Transmission Lcss as a Function of Distance

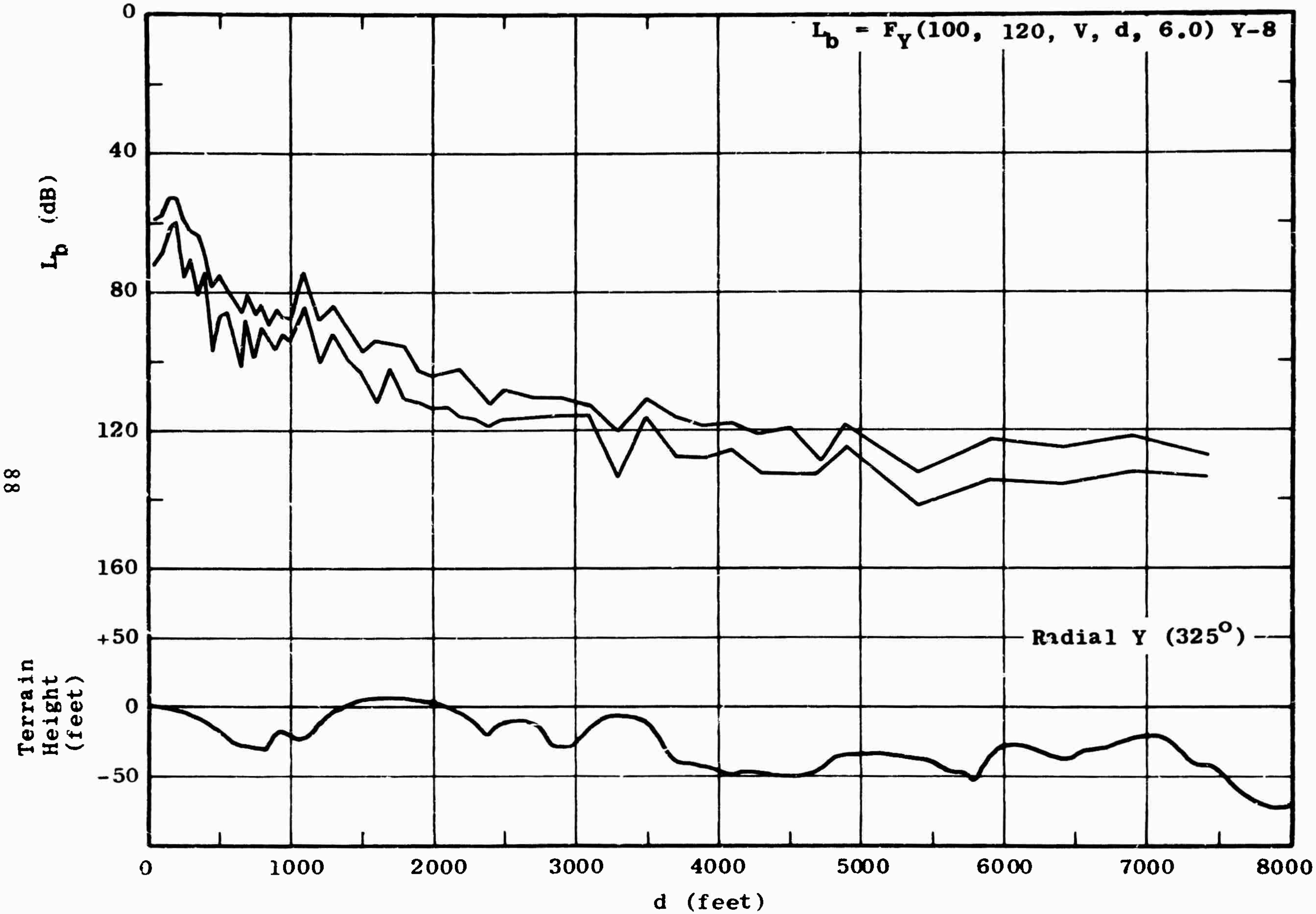

Figure 2.76 Maximum and Minimum Basic Transmission Loss as a Function of Distance

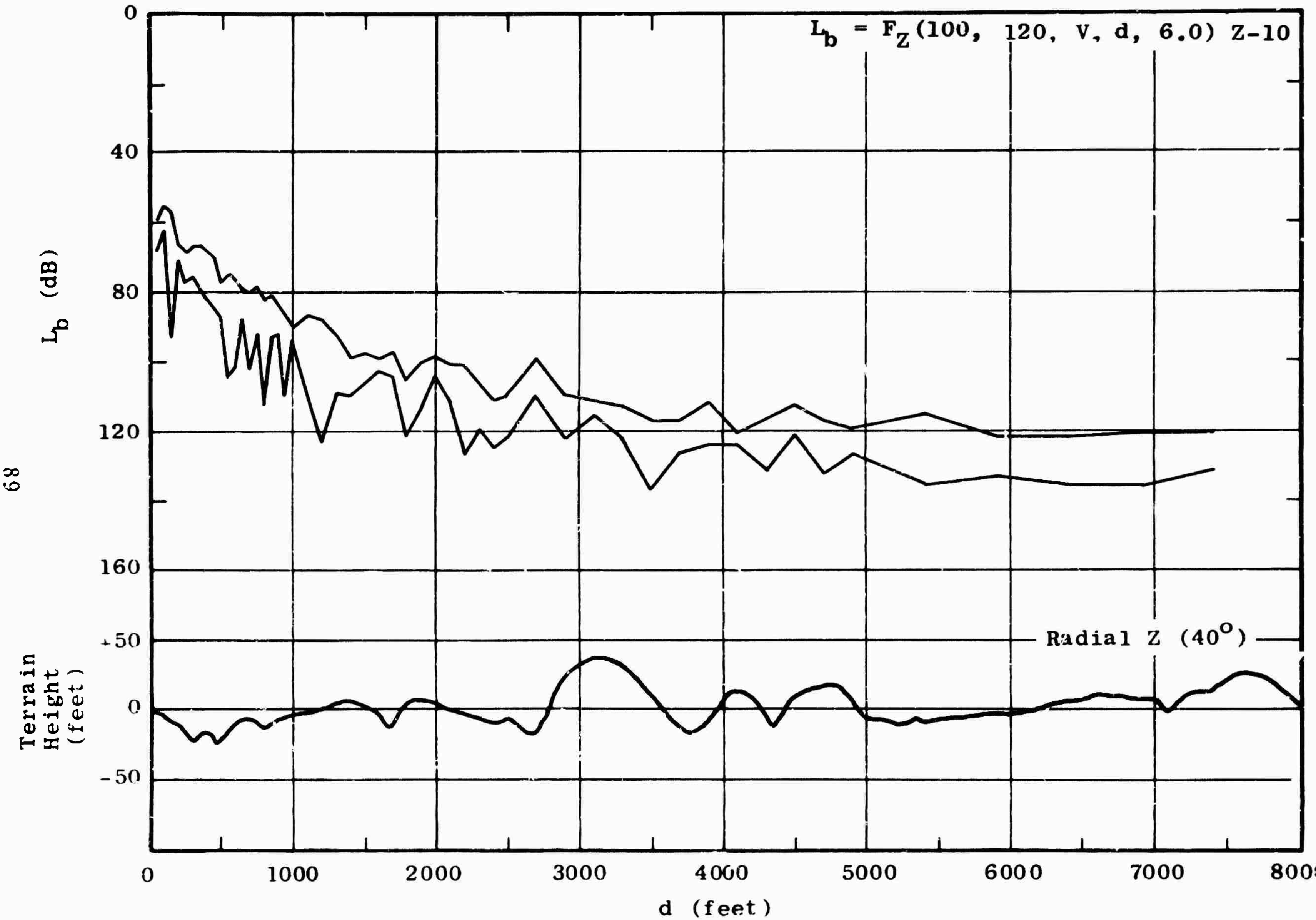

Figure 2.77 Maximum and Minimum Basic Transmission Loss as a Function of Distance

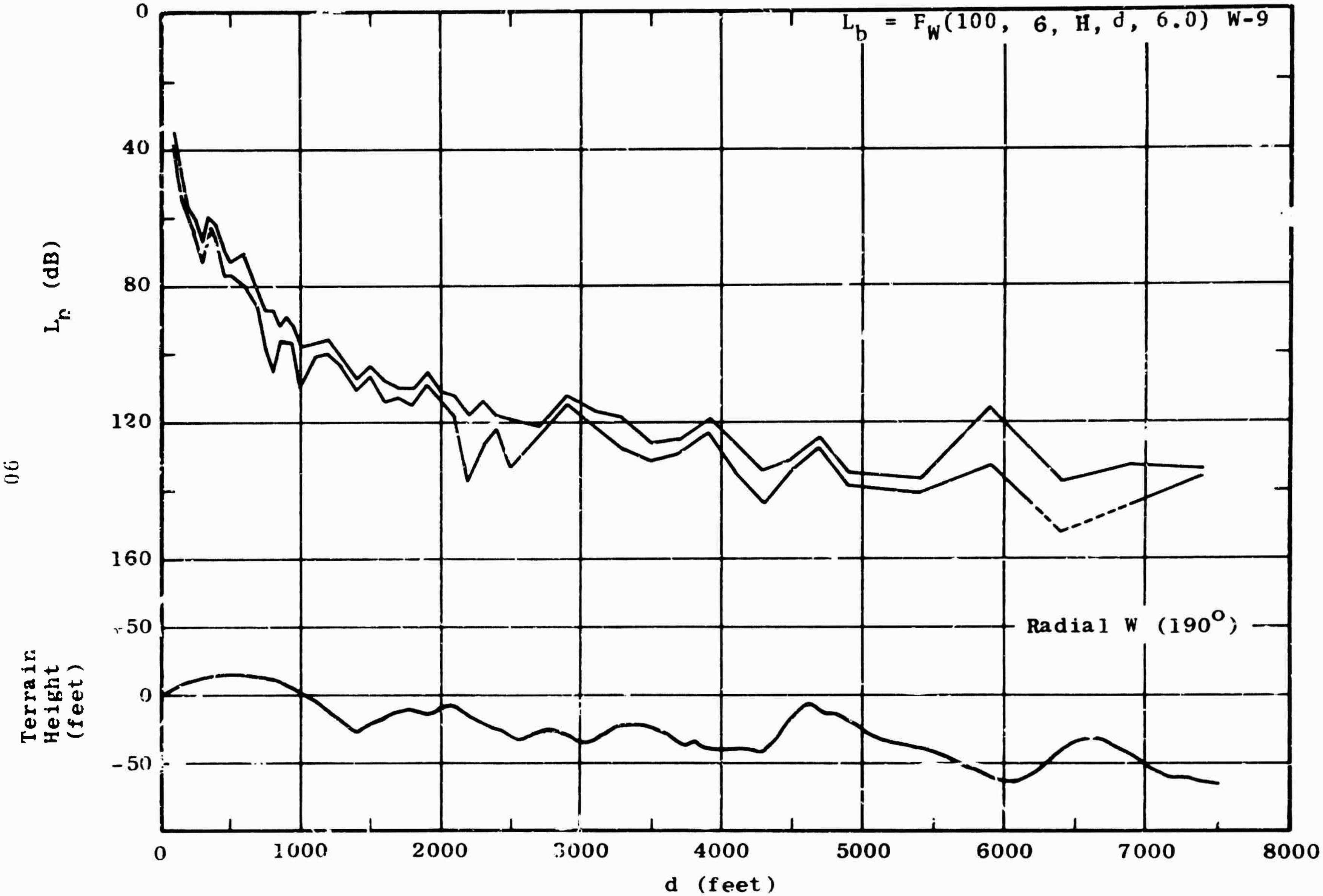

Figure 2.78 Maximum and Minimum Basic Transmission Loss as a Function of Distance

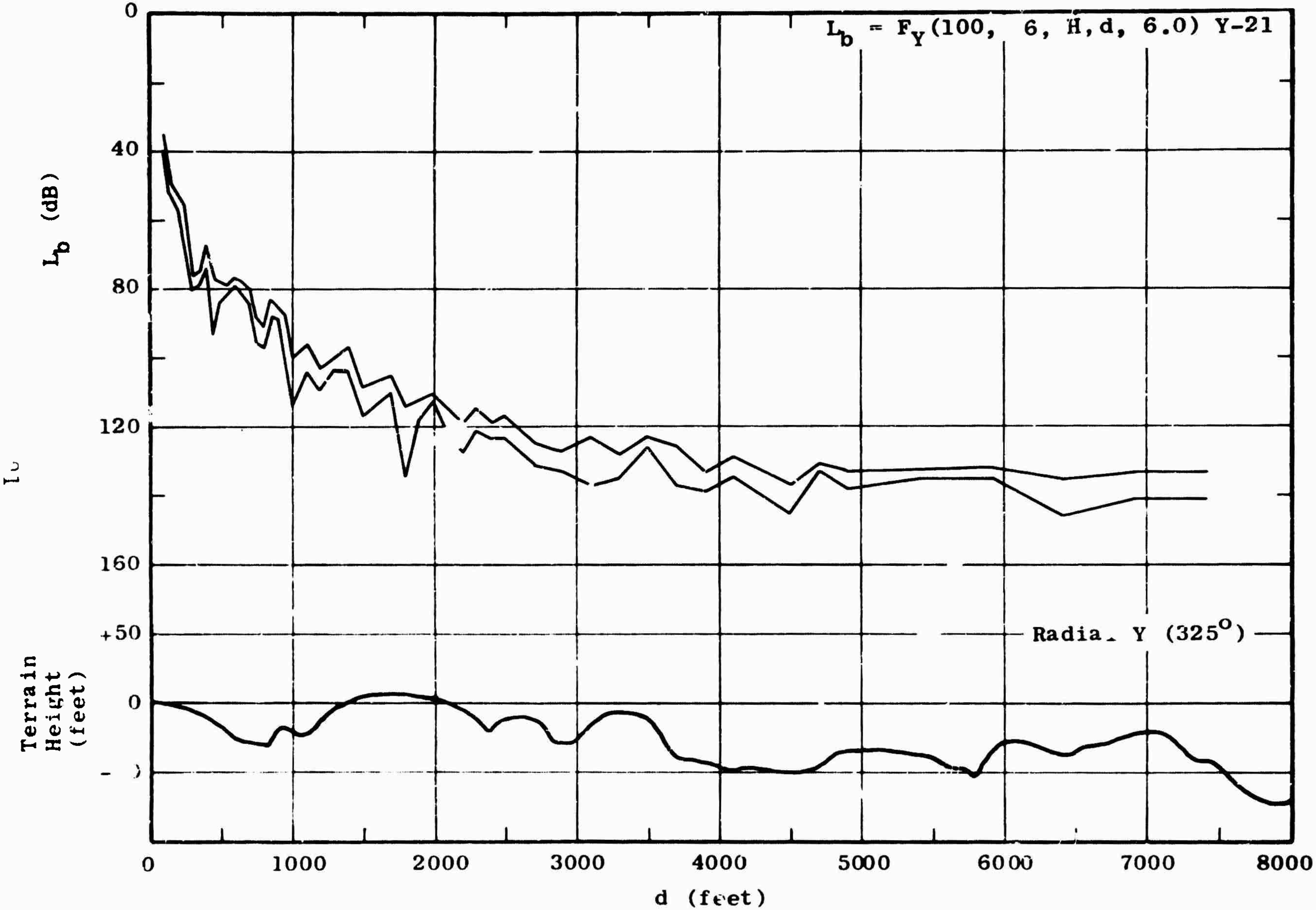

Figure 2.79 Maximum and Minimum Basic Transmission Loss as a Function of Distance

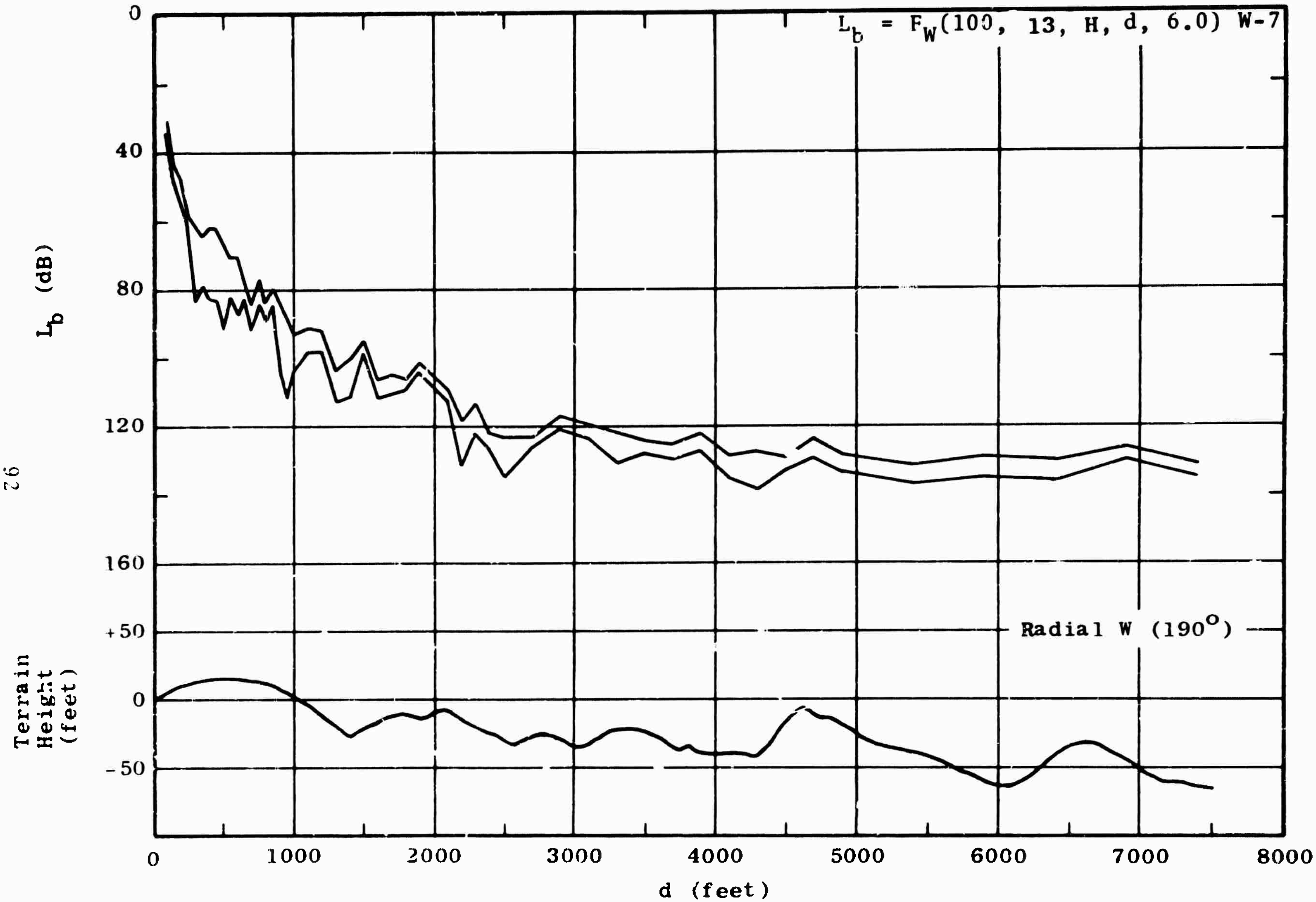

Figure 2.[illegible]0 Maximum and Minimum Basic Transmission Loss as a Function of Distance

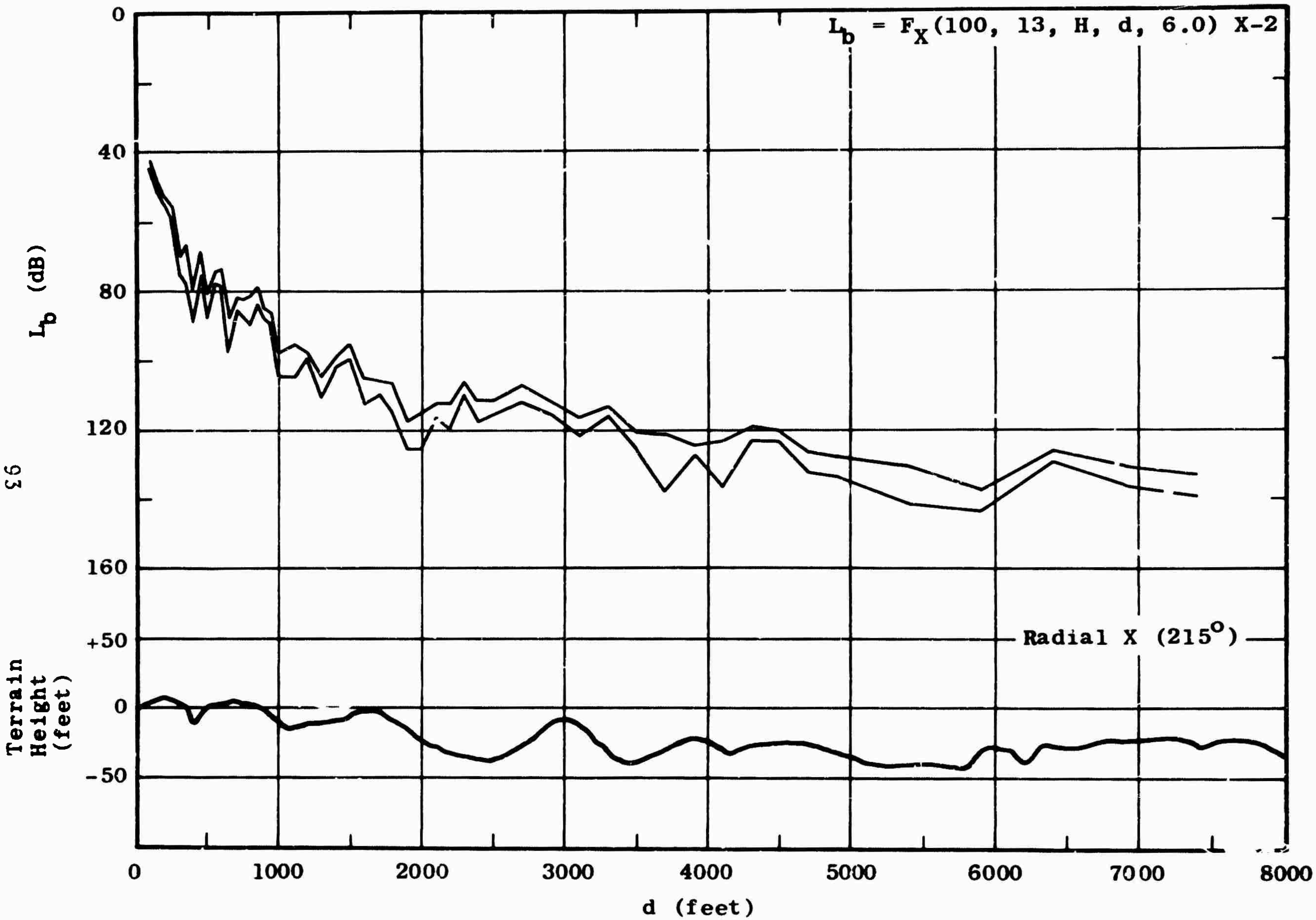

Figure 2.81 Maximum and Minimum Basic Transmission Loss as a Function of Distance

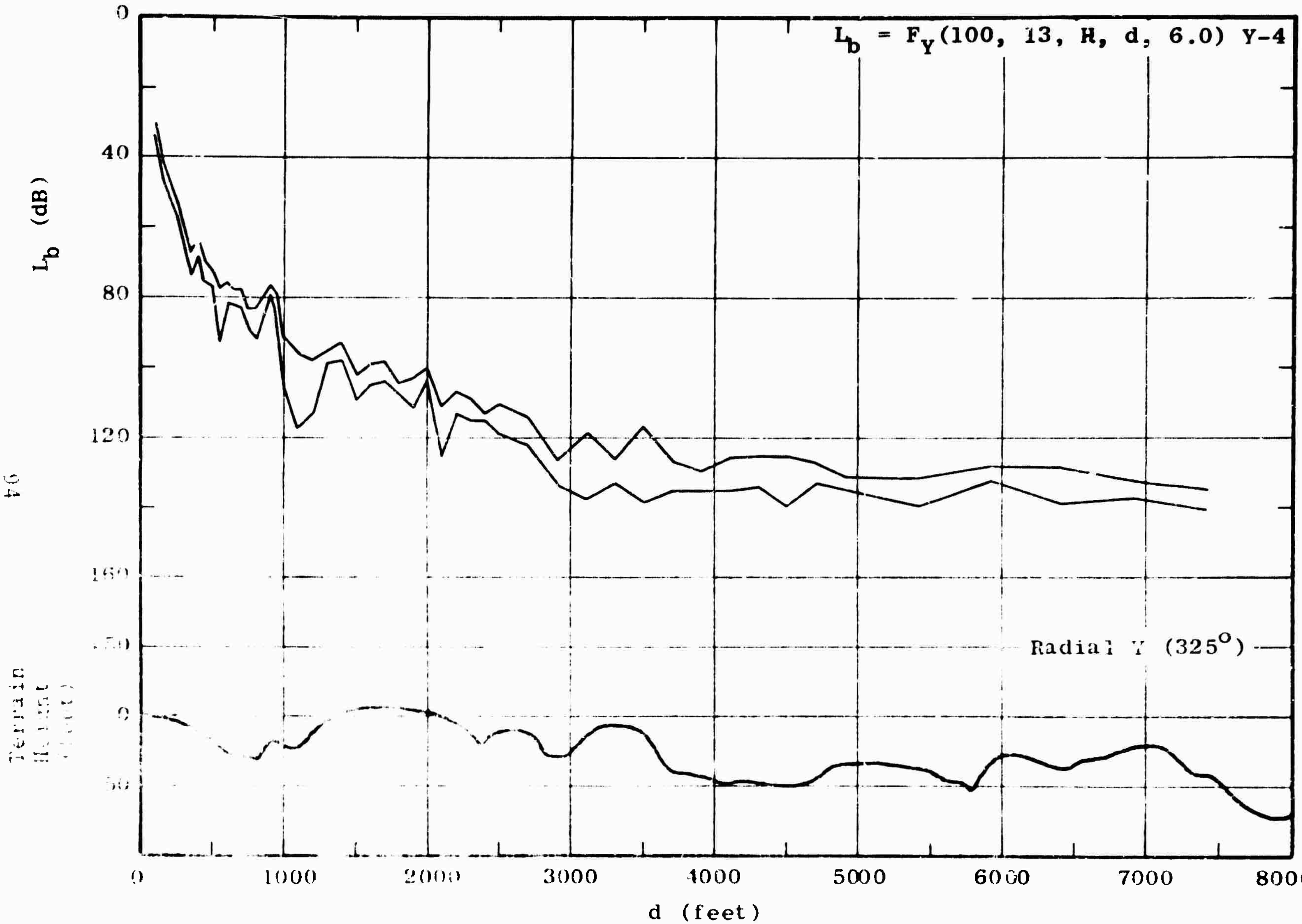

Figure 2.32 Maximum and Minimum Basic Transmission Loss as a Function of Distance

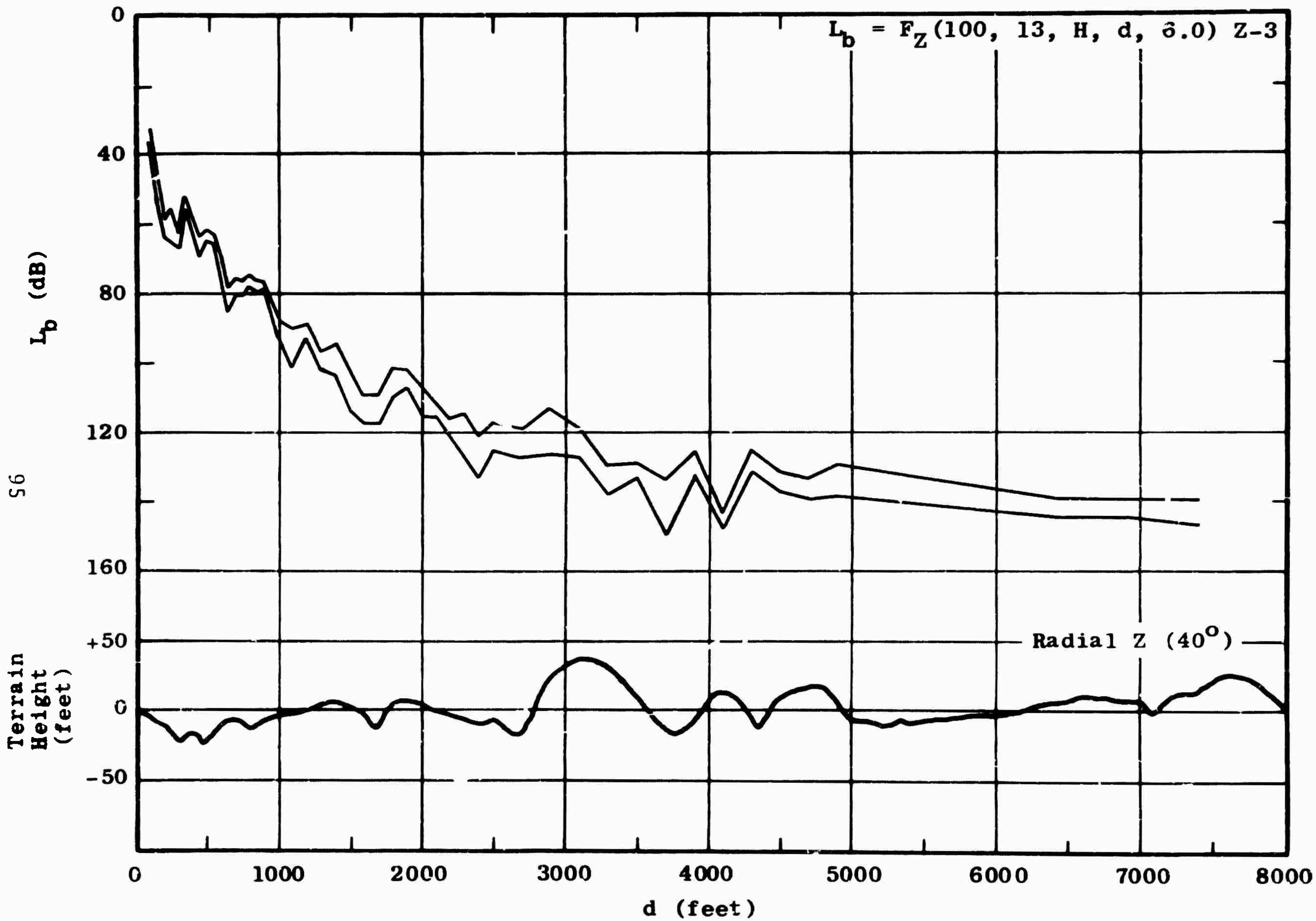

Figure 2.83 Maximum and Minimum Basic Transmission Loss as a Function of Distance

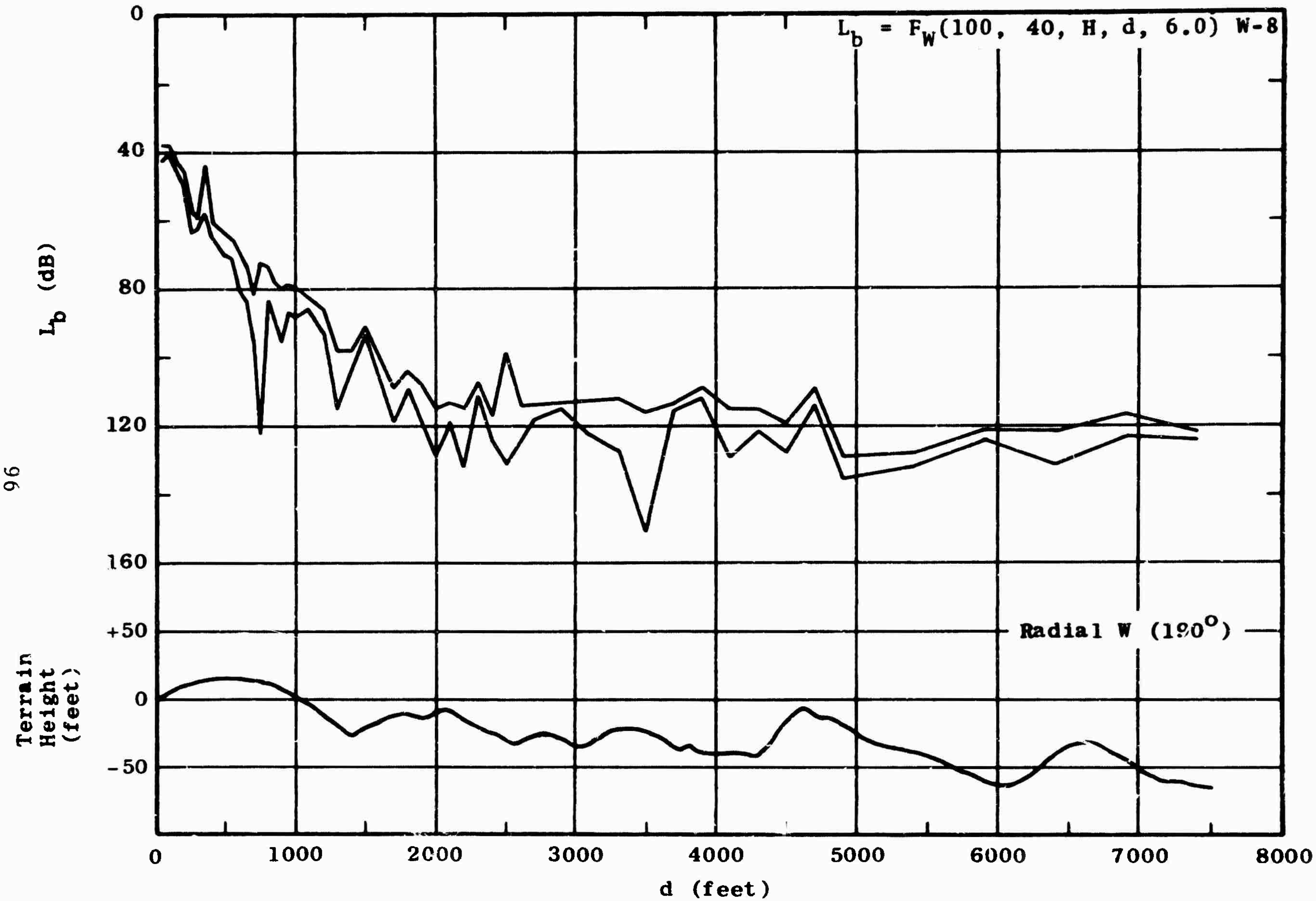

Figure 2.84 Maximum and Minimum Basic Transmission Loss as a Function of Distance

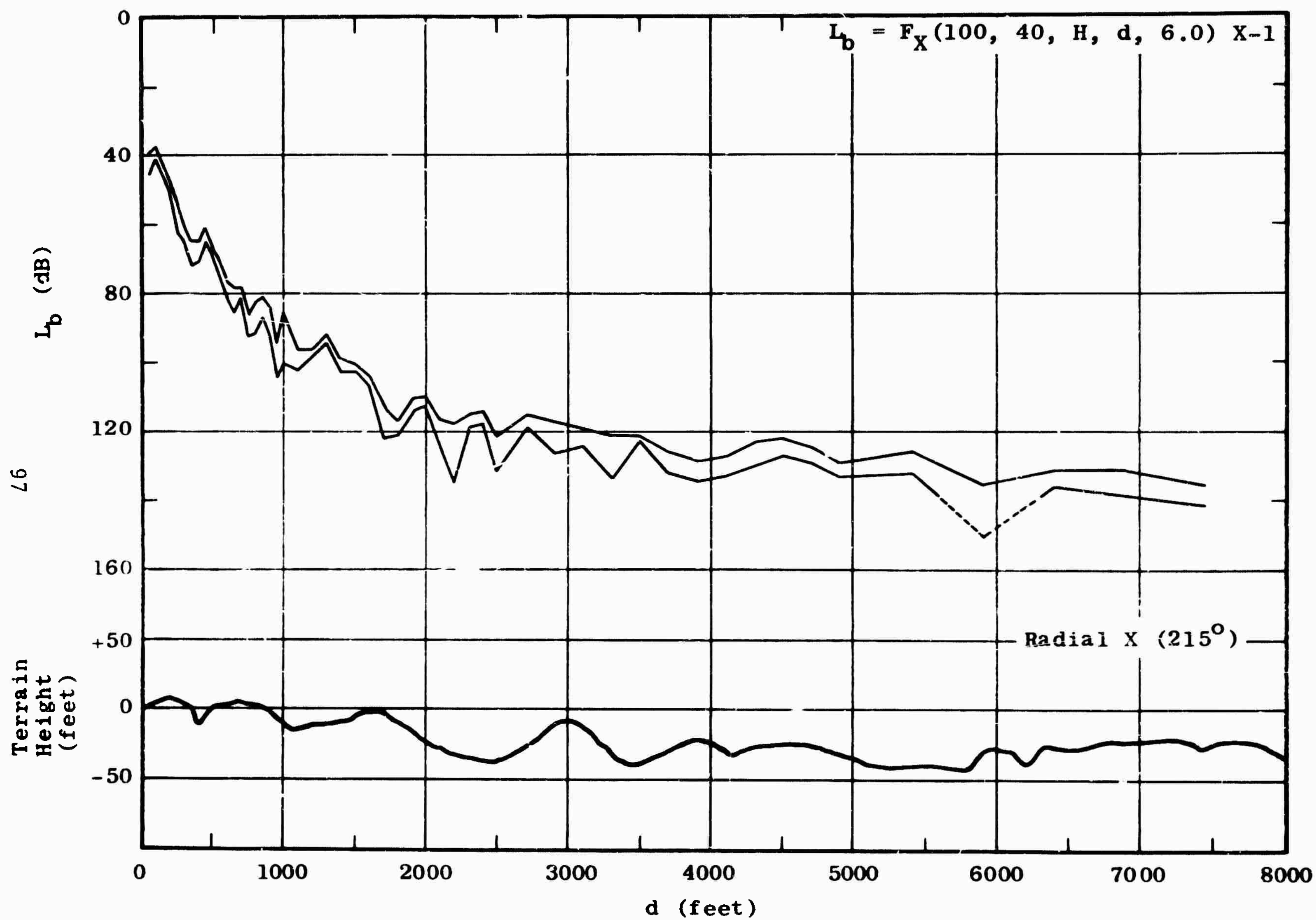

Figure 2.85 Maximum and Minimum Basic Transmission Loss as a Function of Distance

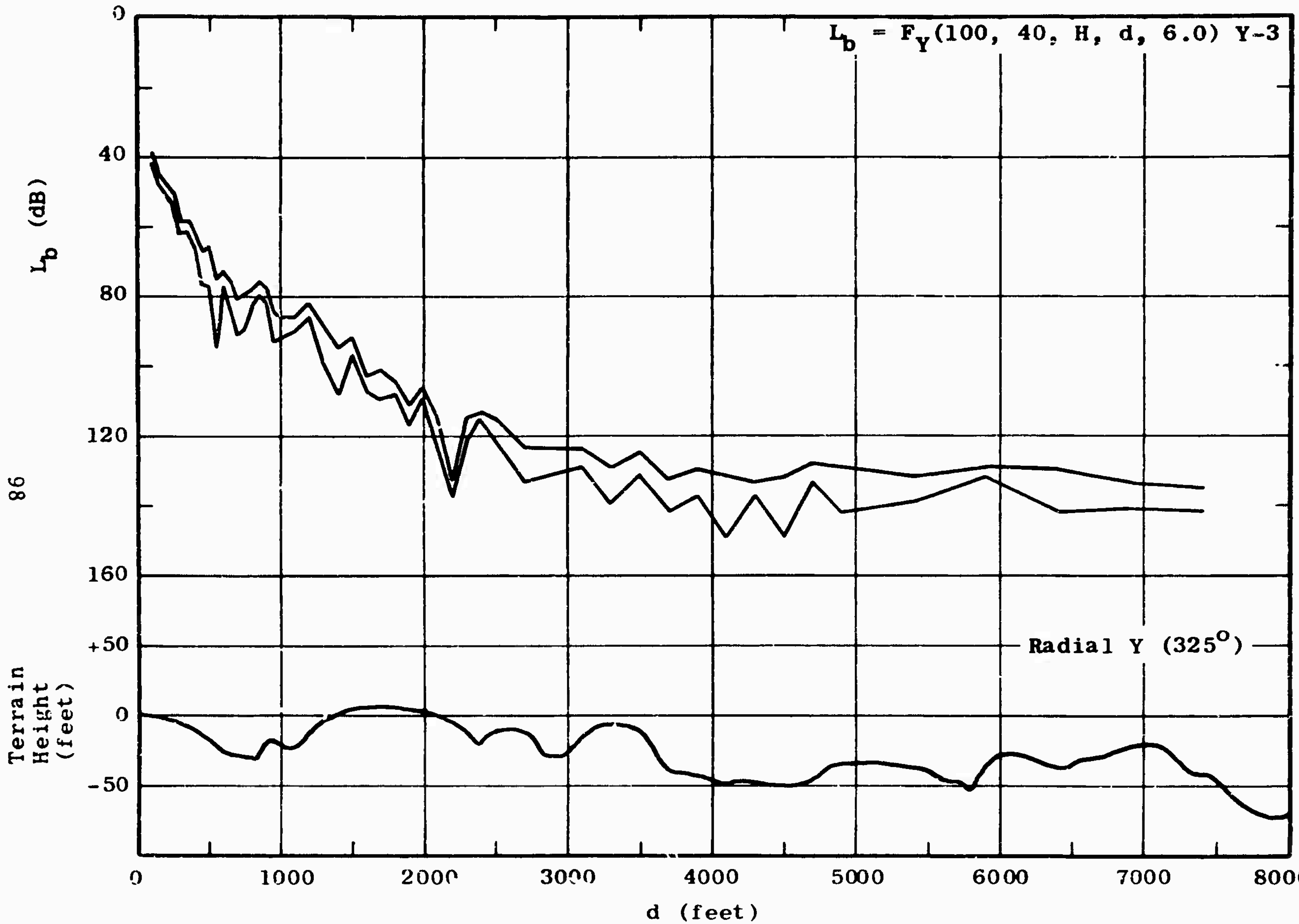

Figure 2.86 Maximum and Minimum Basic Transmission Loss as a Function of Distance

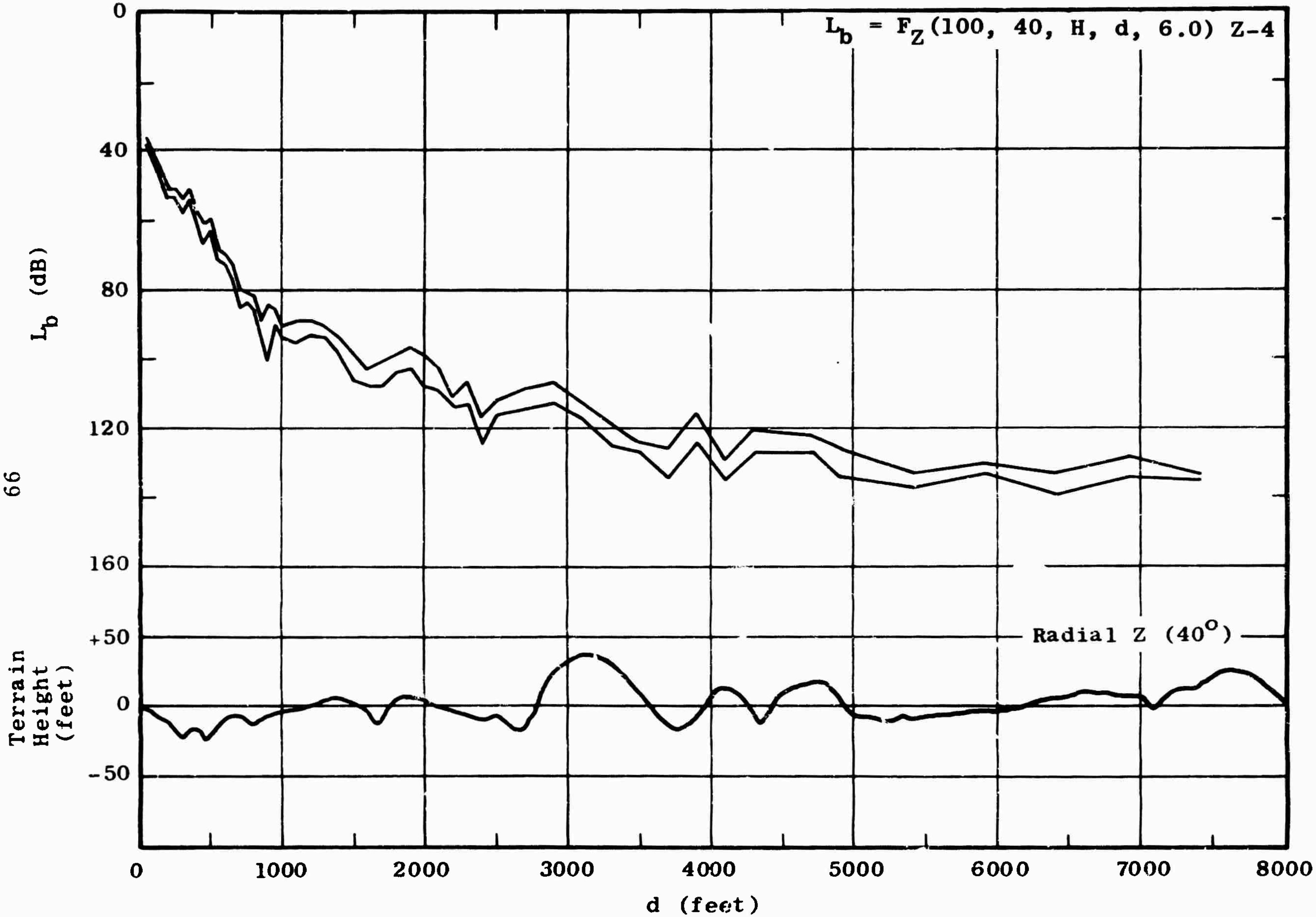

Figure 2.87 Maximum and Minimum Basic Transmission Loss as a Function of Distance

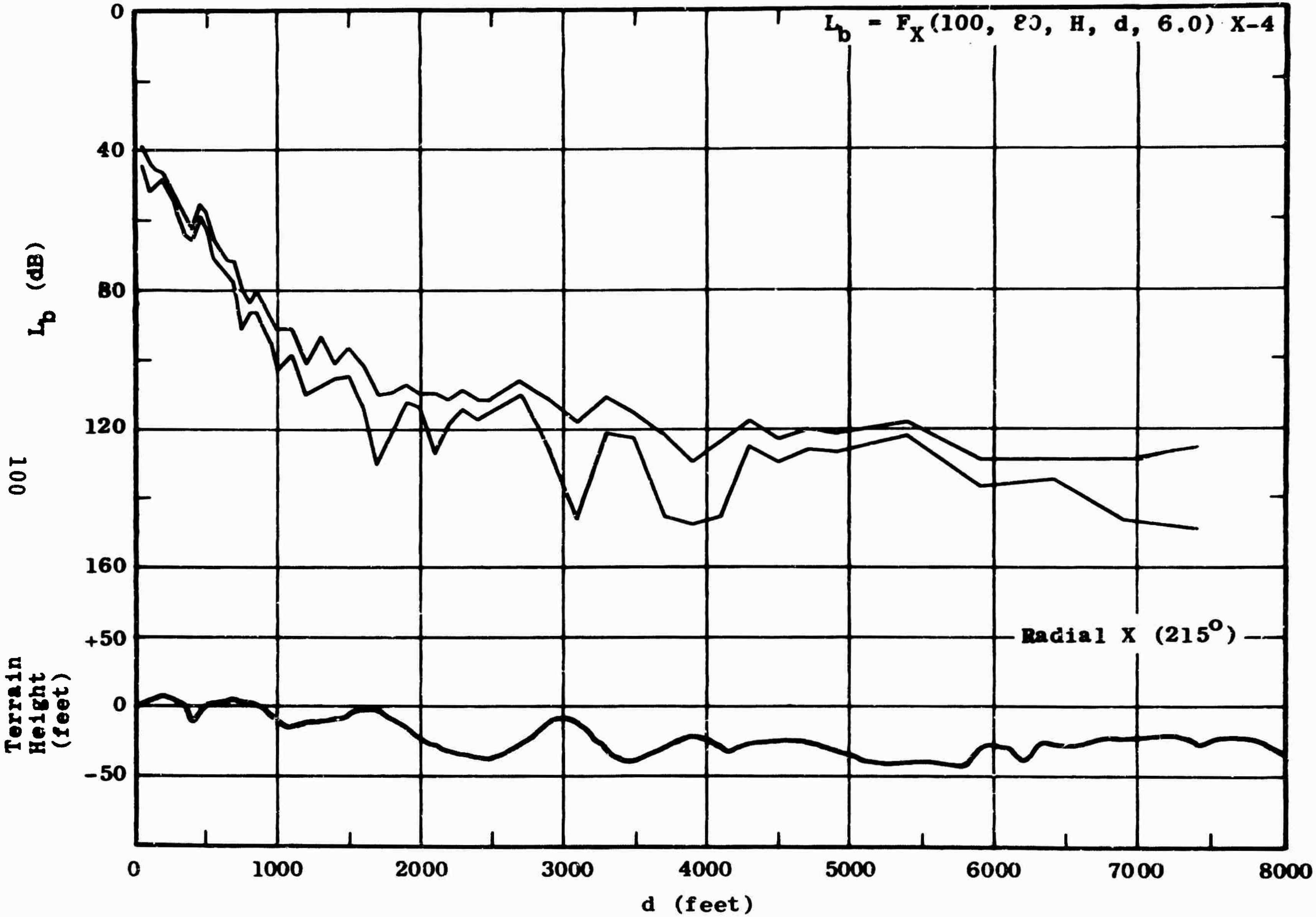

Figure 2.88 Maximum and Minimum Basic Transmission Loss as a Function of Distance

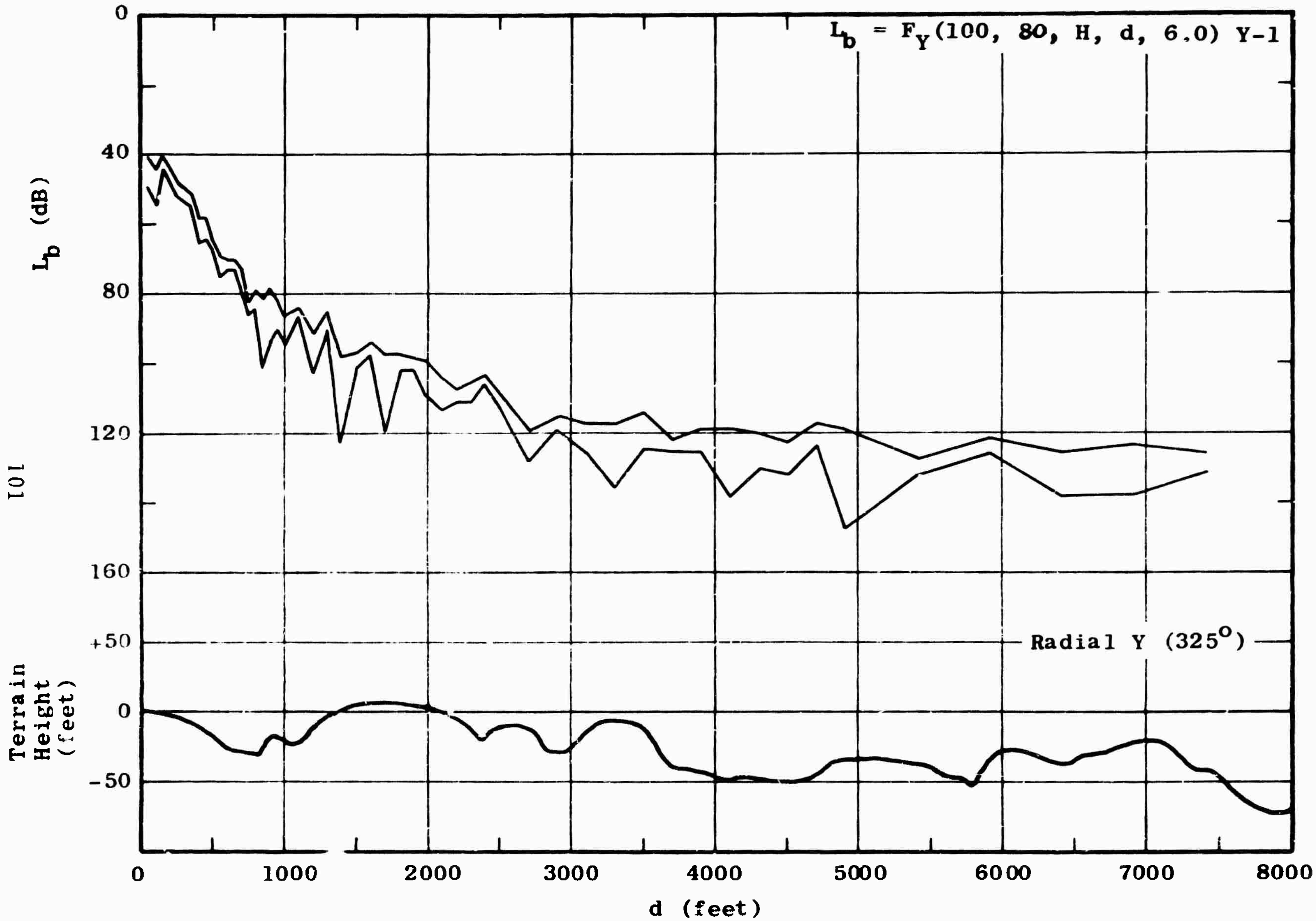

Figure 2.89 Maximum and Minimum Basic Transmission Loss as a Function of Distance

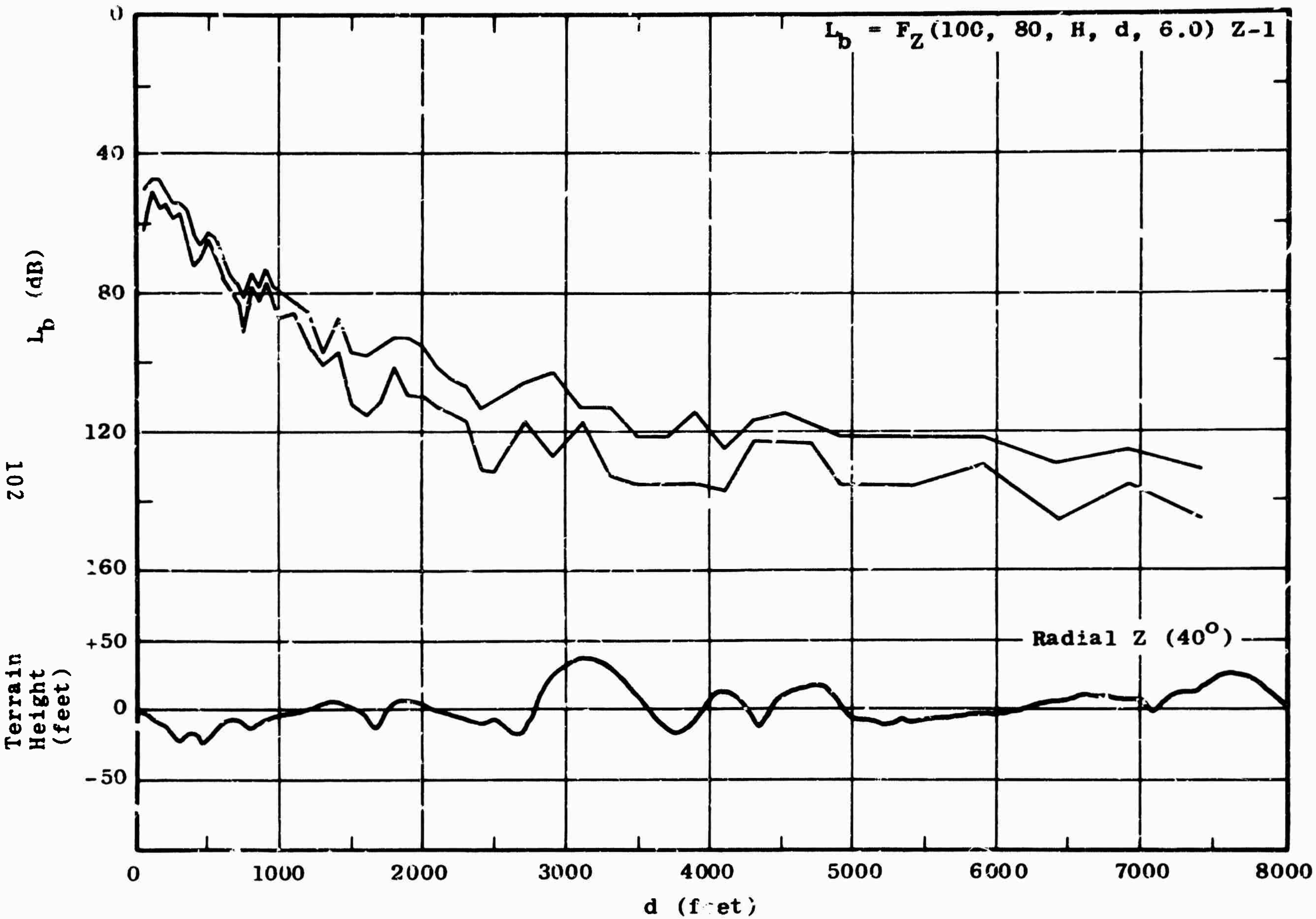

Figure 2.90 Maximum and Minimum Basic Transmission Loss as a Function of Distance

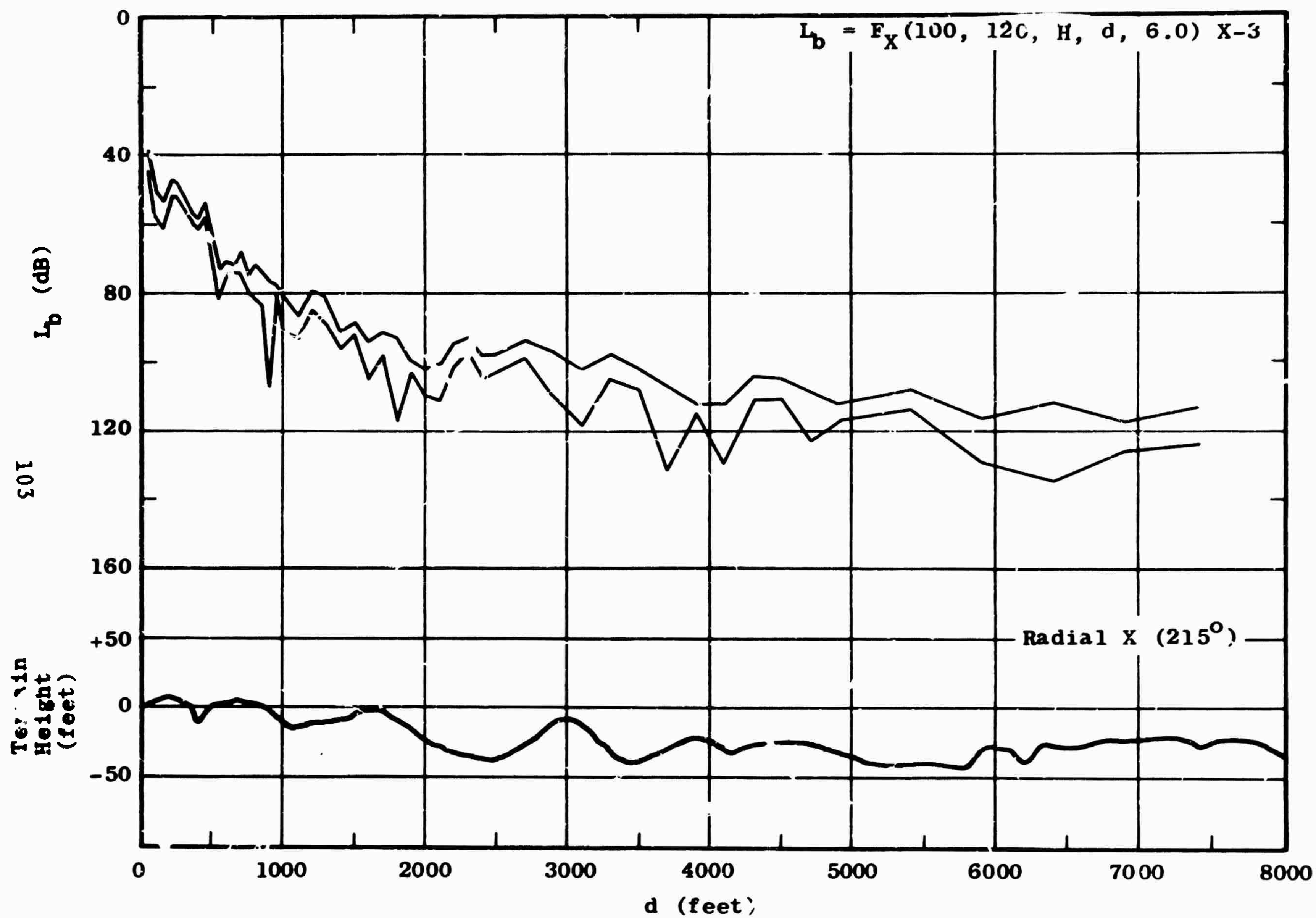

Figure 2.91 Maximum and Minimum Basic Transmission Loss as a Function of Distance

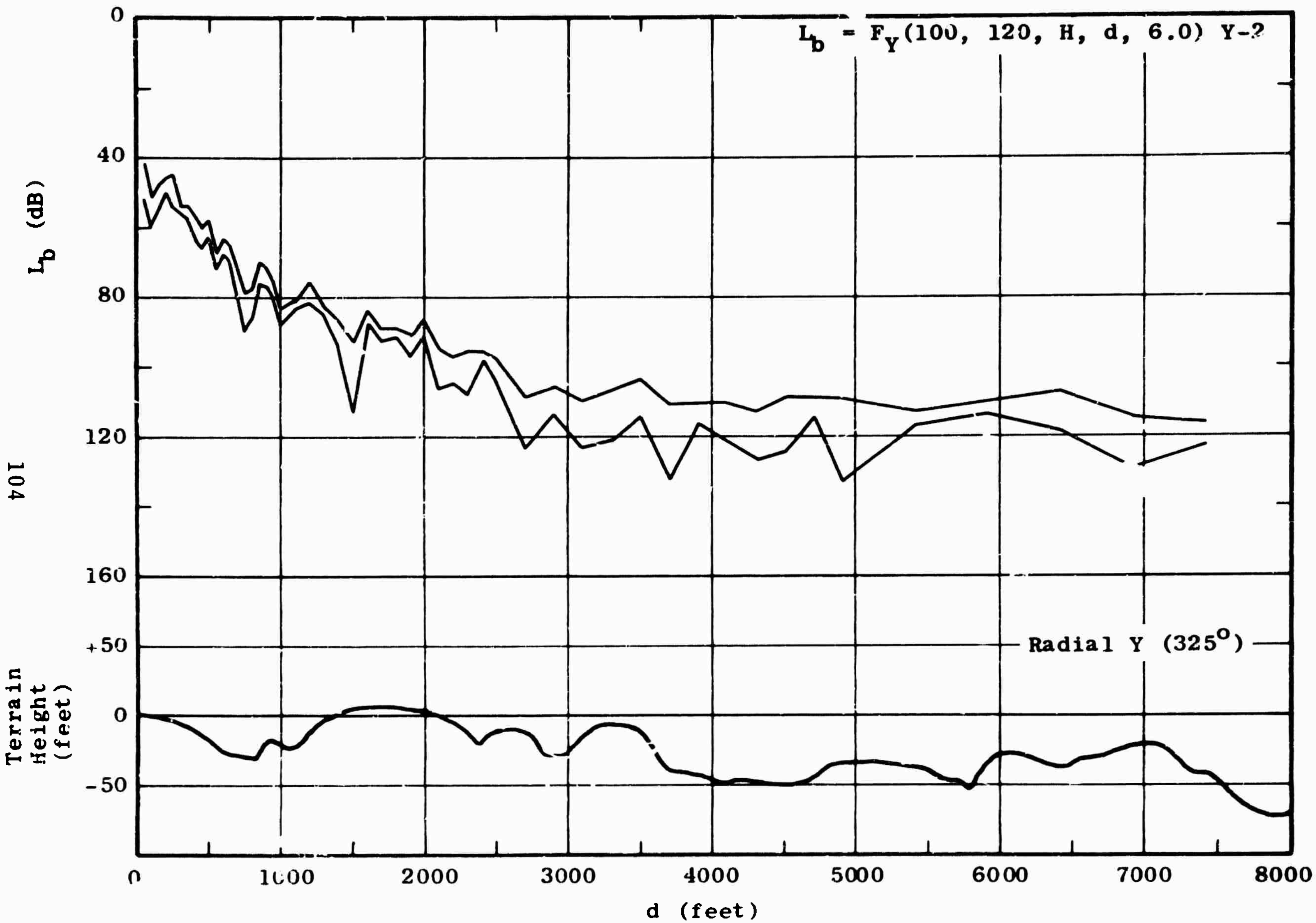

Figure 2.92 Maximum and Minimum Basic Transmission Loss as a Function of Distance

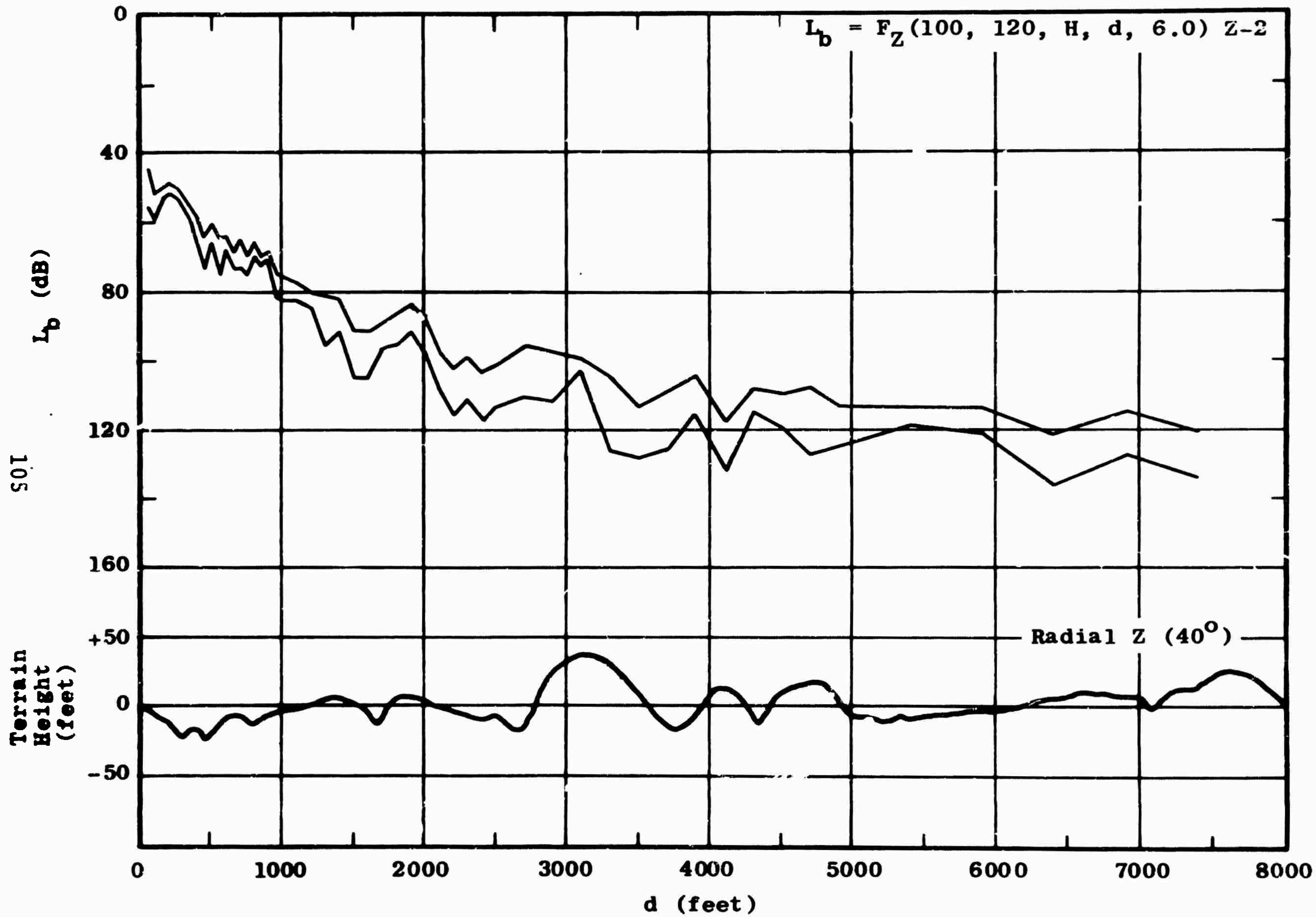

Figure 2.93 Maximum and Minimum Basic Transmission Loss as a Function of Distance

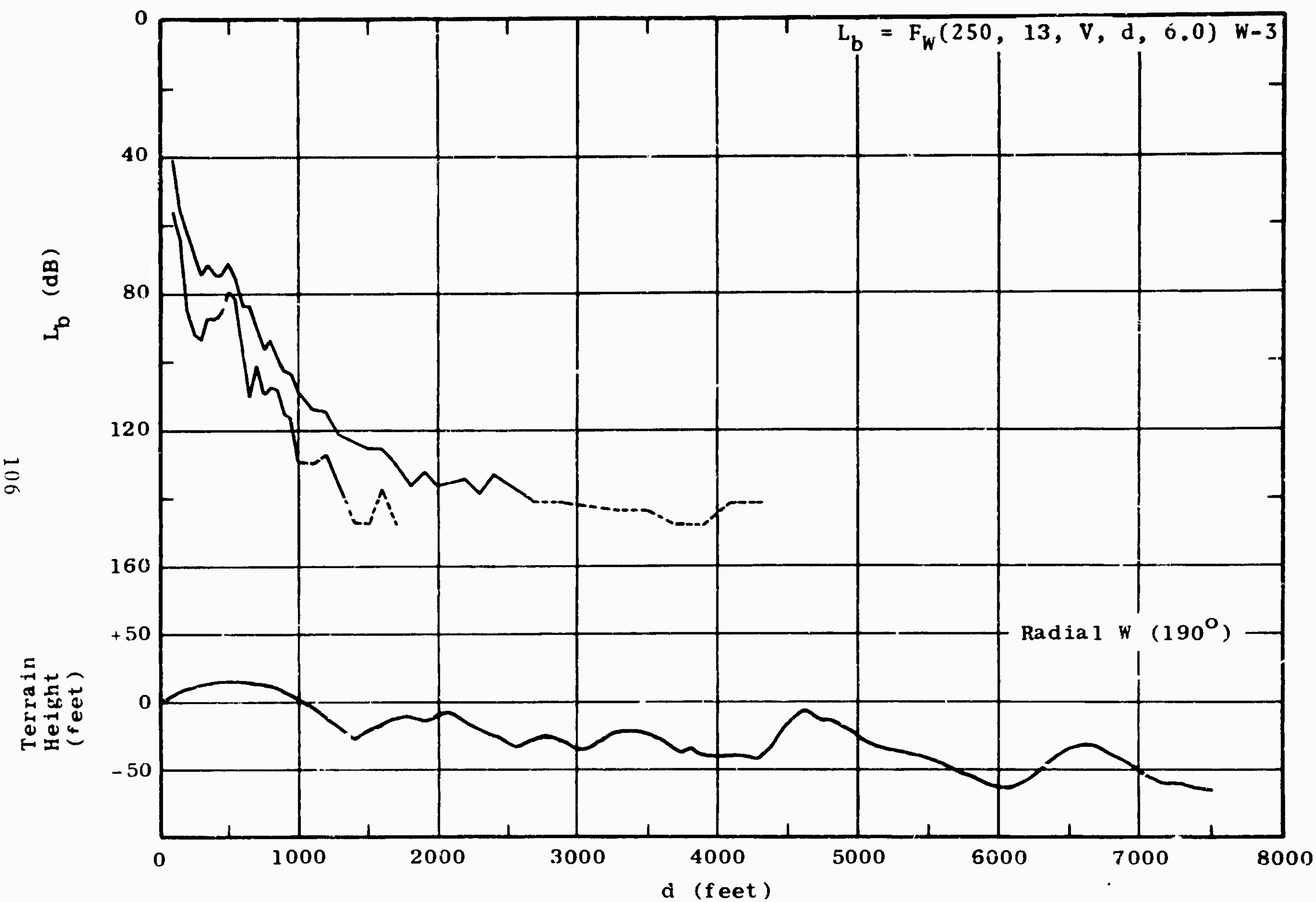

Figure 2.94 Maximum and Minimum Basic Transmission Loss as a Function of Distance

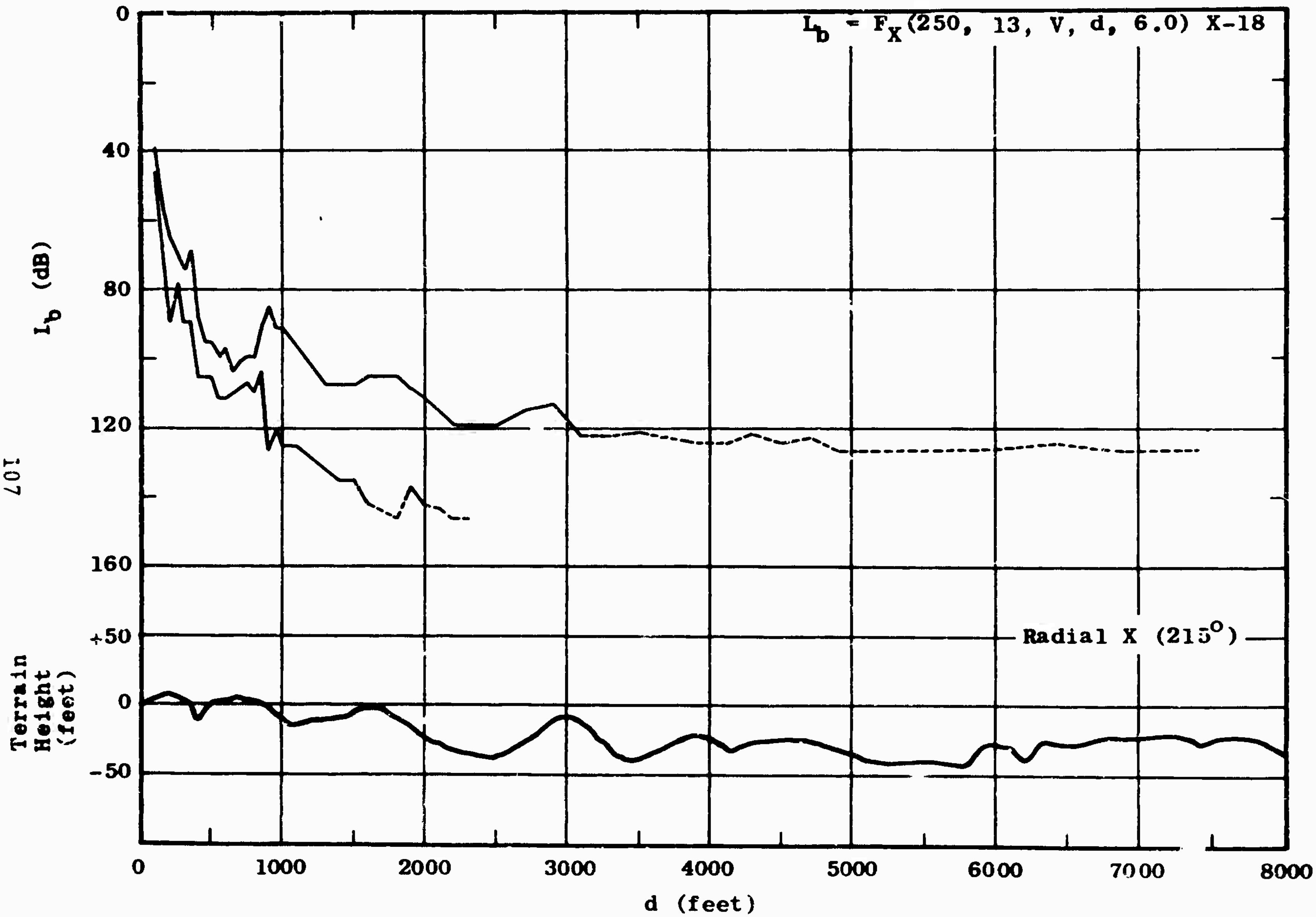

Figure 2.95 Maximum and Minimum Basic Transmission Loss as a Function of Distance

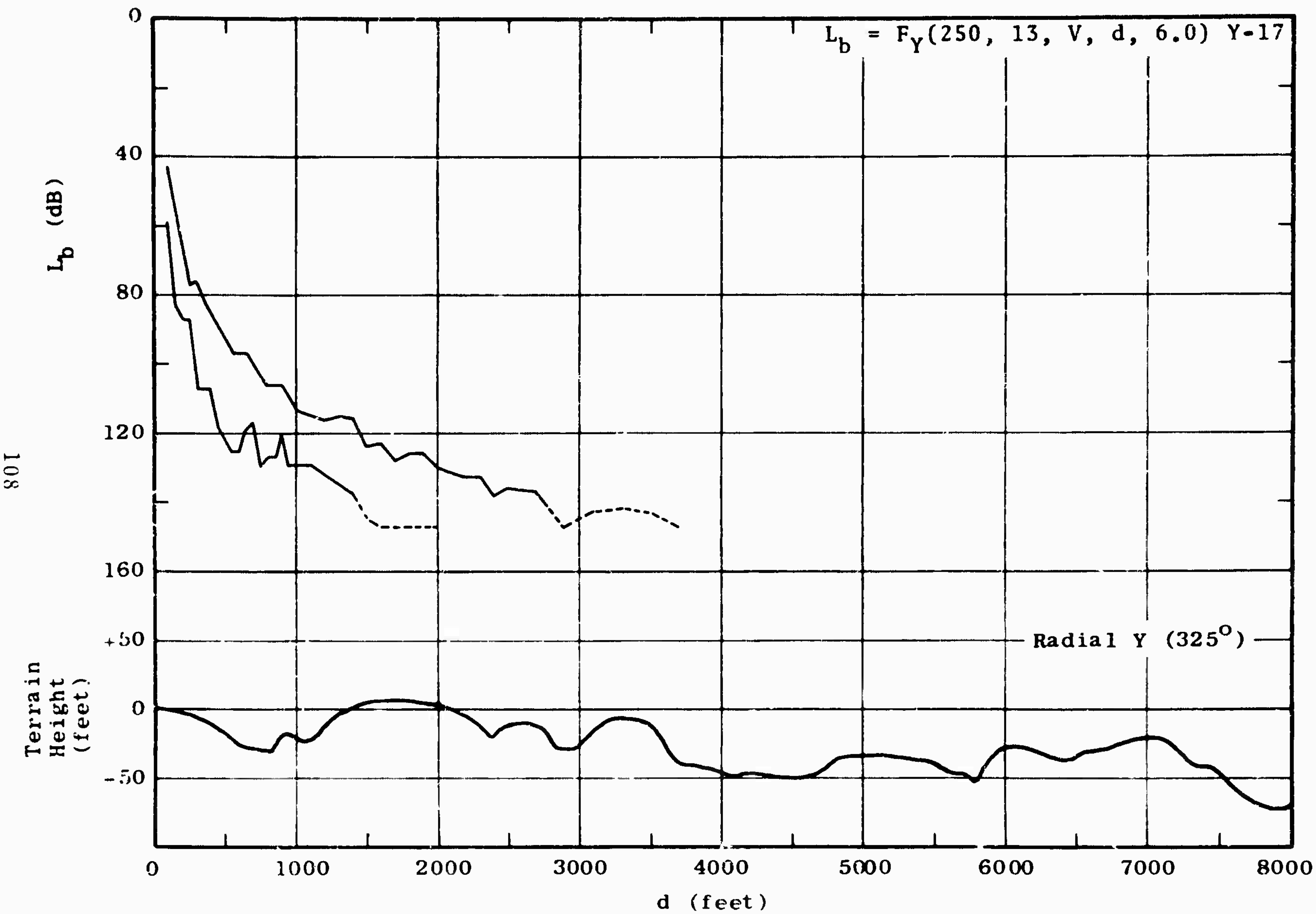

Figure 2.96 Maximum and Minimum Basic Transmission Loss as a Function of Distance

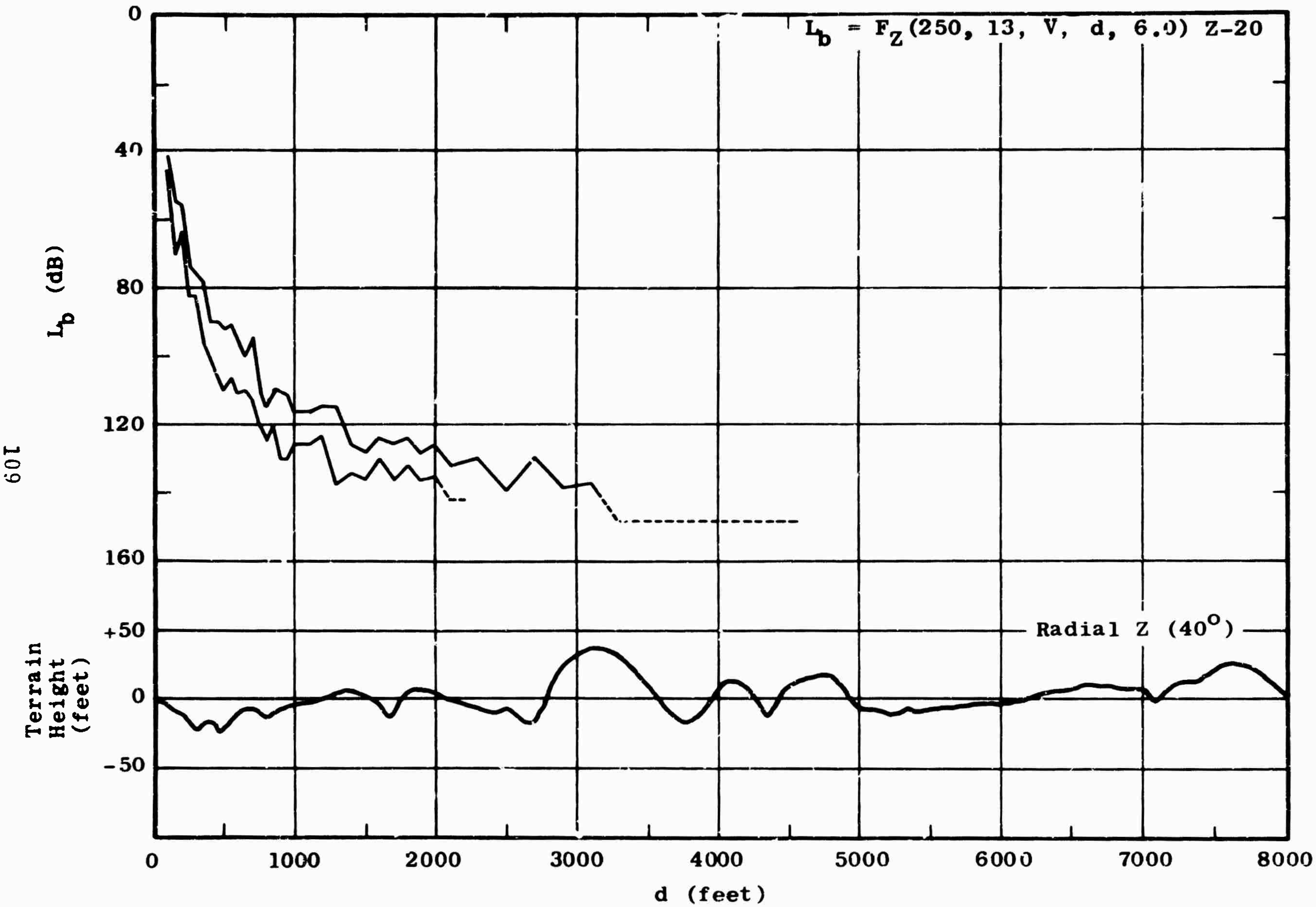

Figure 2.97 Maximum and Minimum Basic Transmission Loss as a Function of Distance

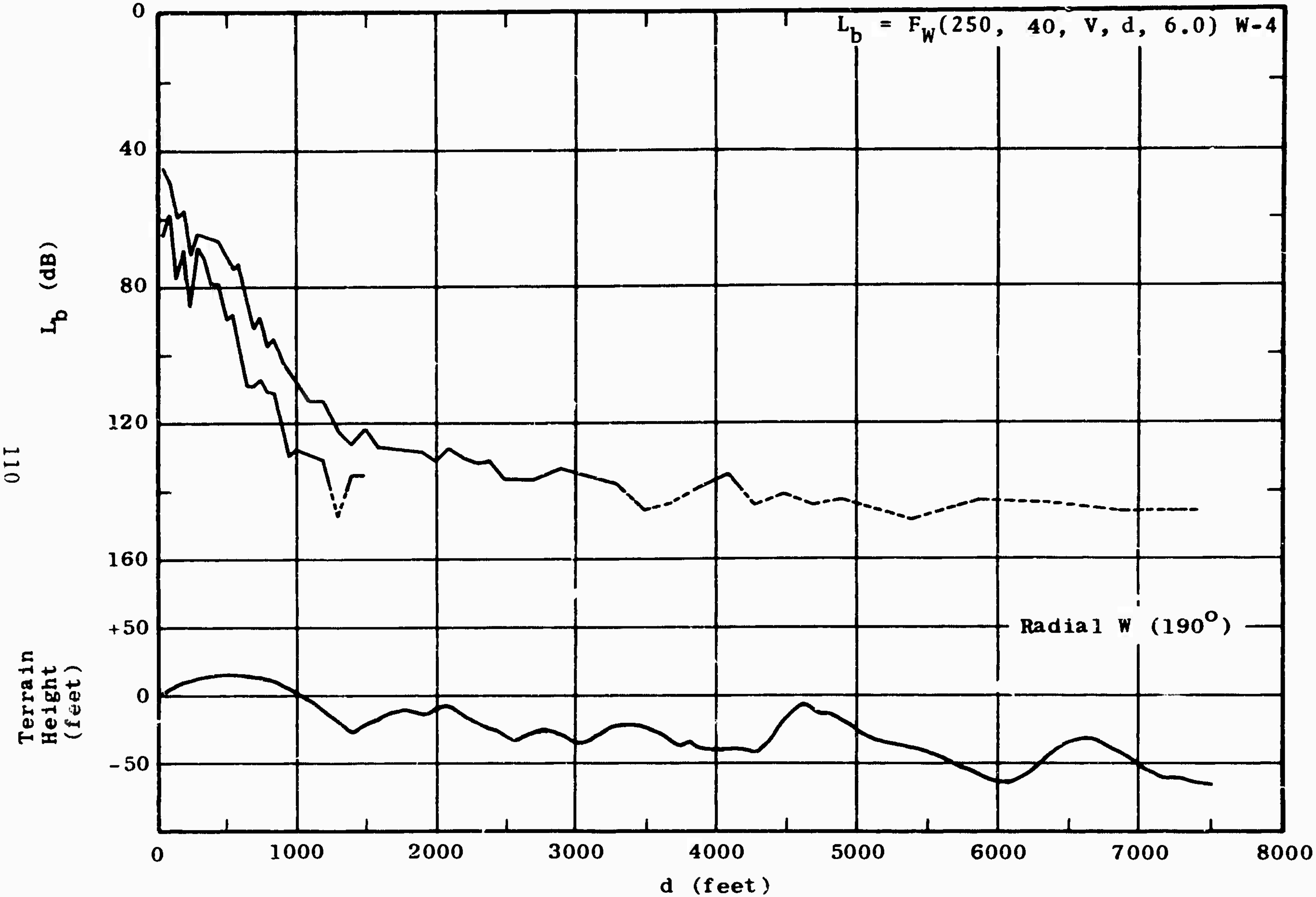

Figure 2.98 Maximum and Minimum Basic Transmission Loss as a Function of Distance

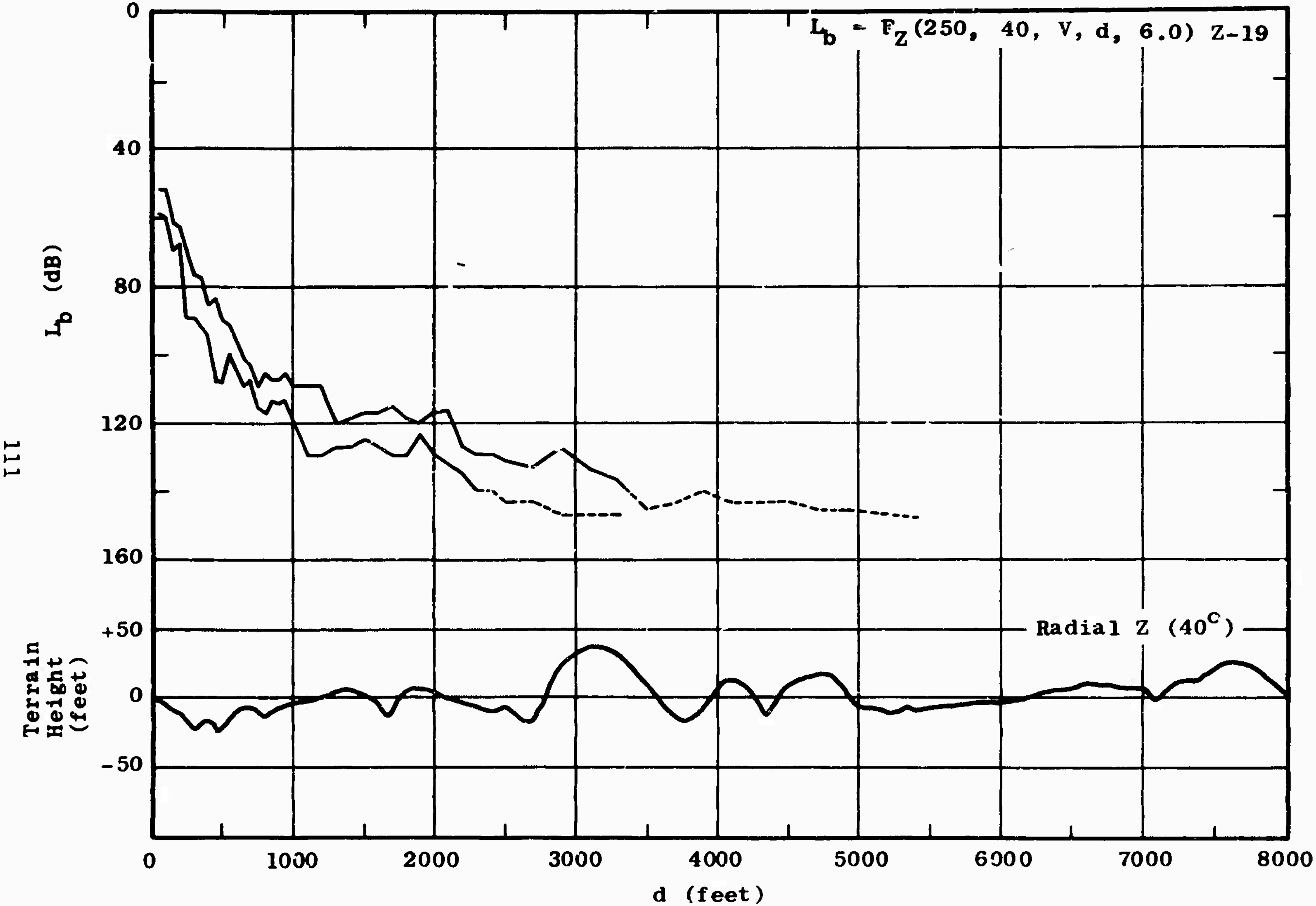

Figure 2.99 Maximum and Minimum Basic Transmission Loss as a Function of Distance

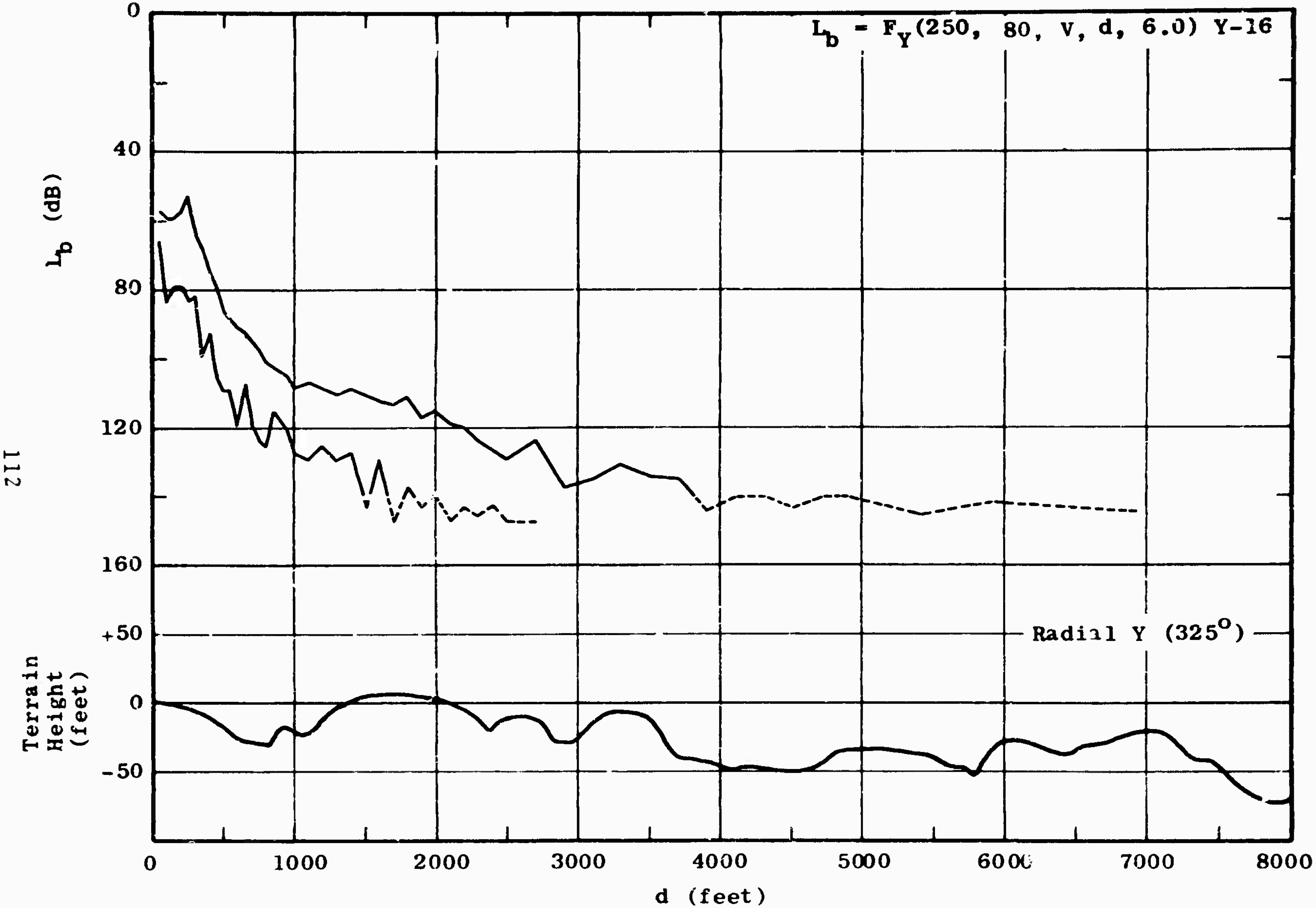

Figure 2.100 Maximum and Minimum Basic Transmission Loss as a Function of Distance

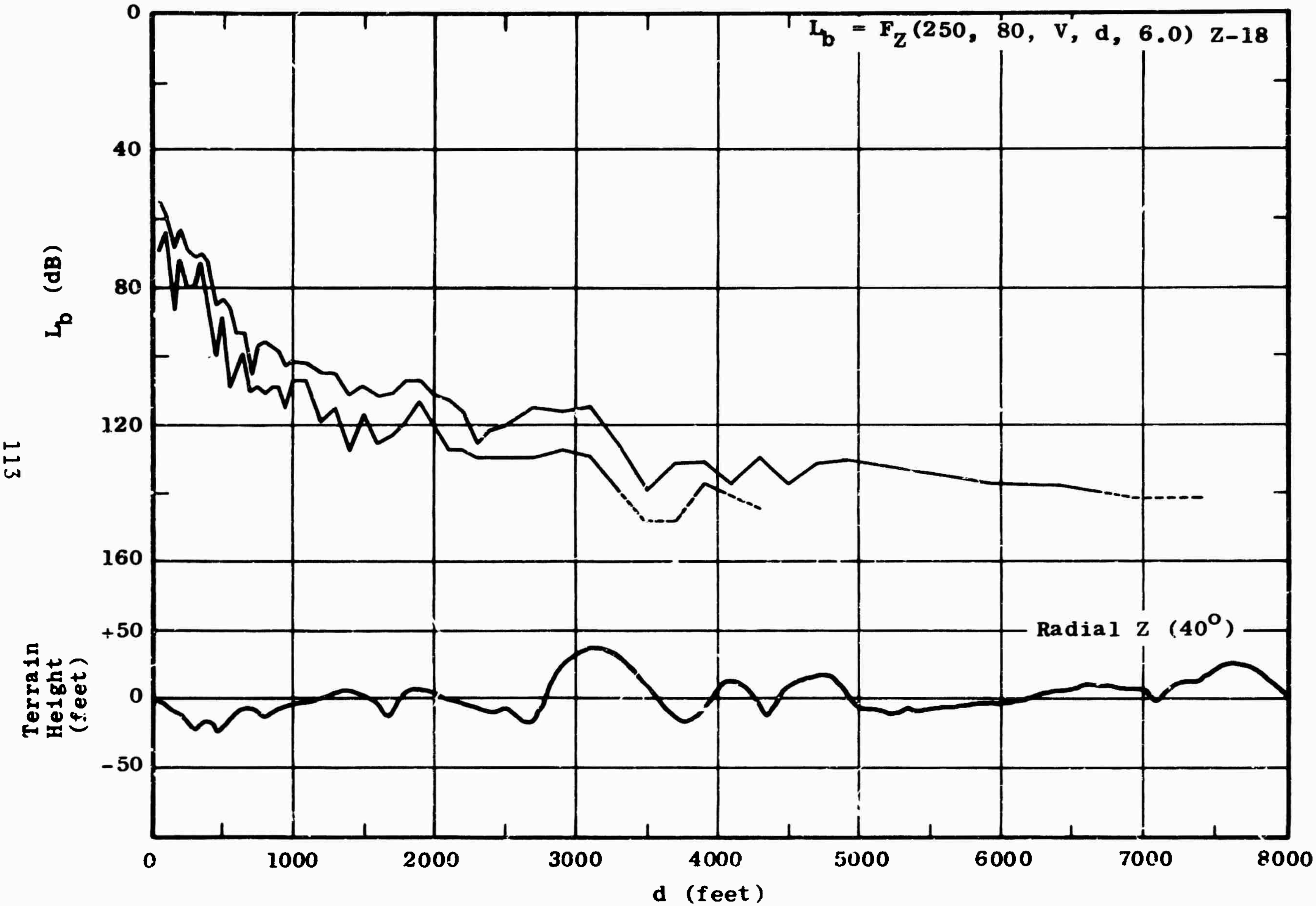

Figure 2.101 Maximum and Minimum Basic Transmission Loss as a Function of Distance

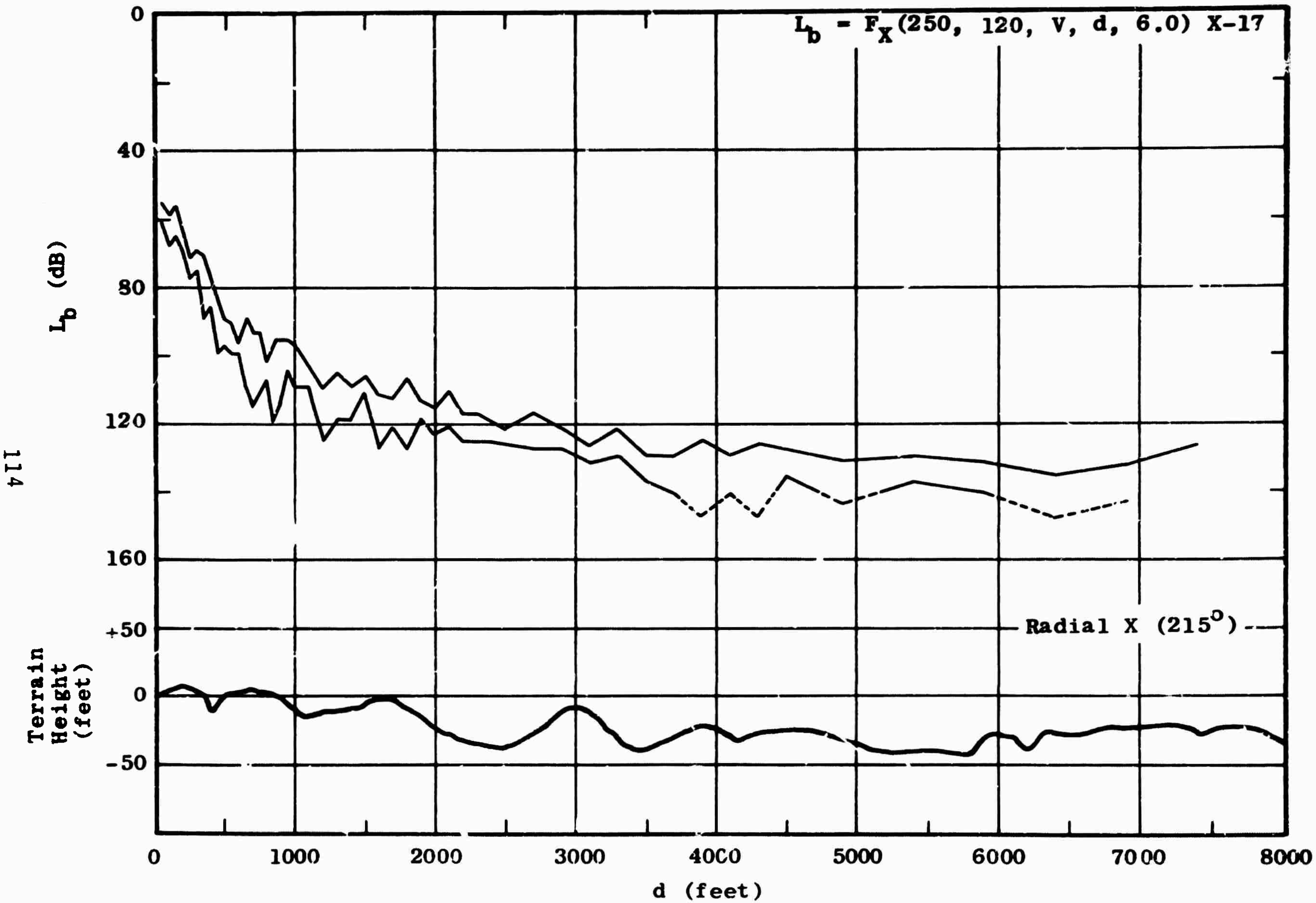

Figure 2.102 Maximum and Minimum Basic Transmission Loss as a Function of Distance

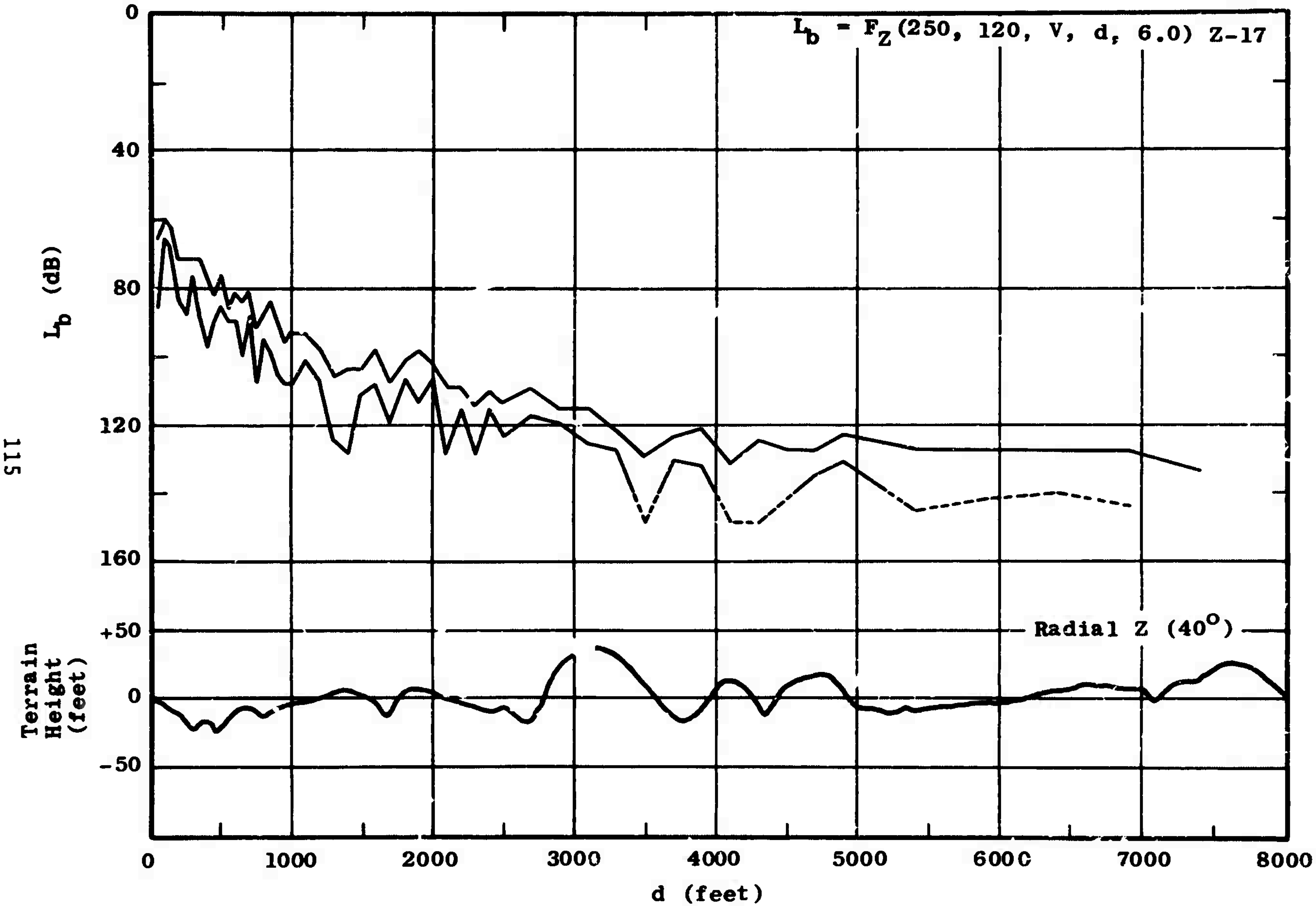

Figure 2.103 Maximum and Minimum Basic Transmission Loss as a Function of Distance

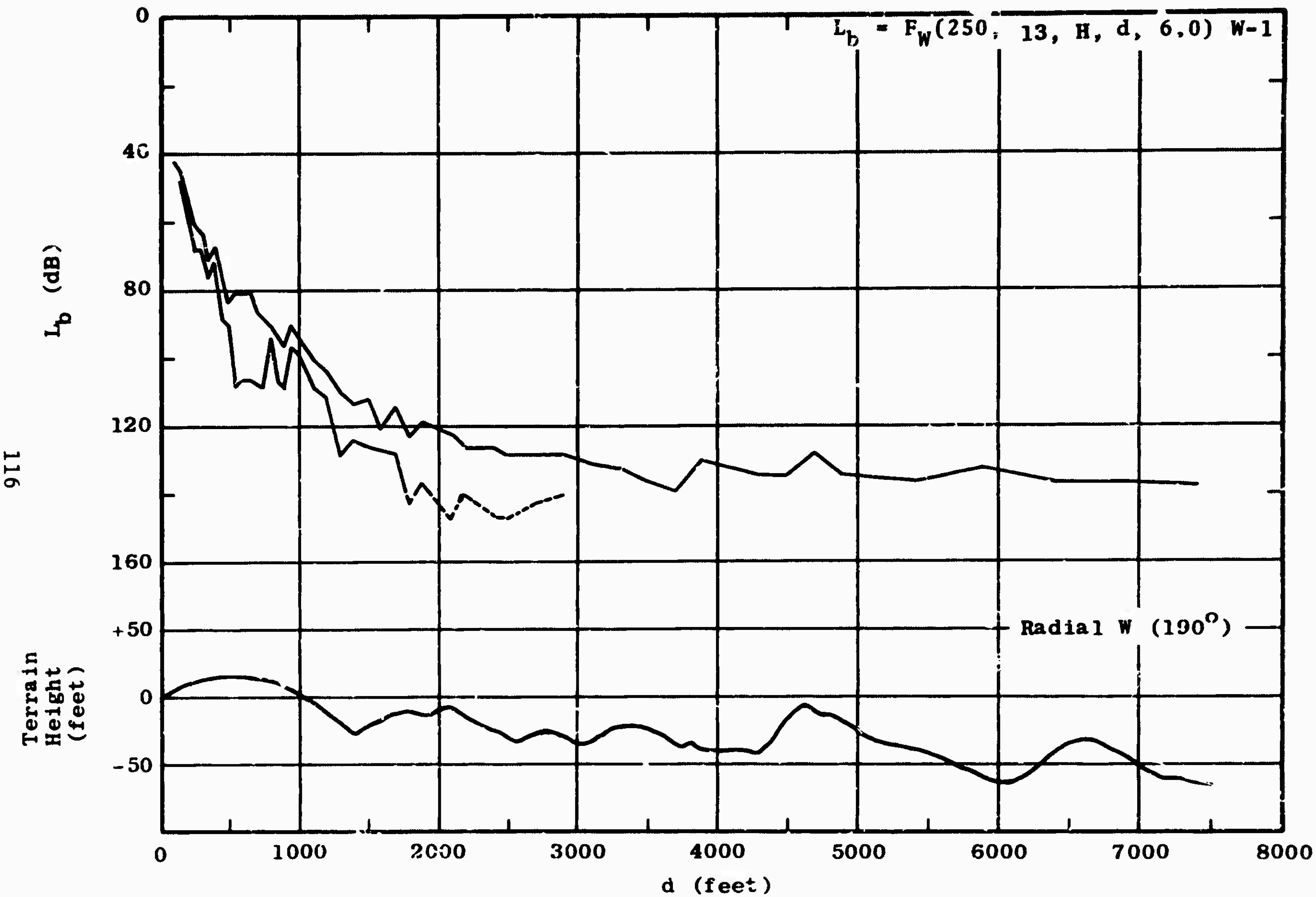

Figure 2.104 Maximum and Minimum Basic Transmission Loss as a Function of Distance

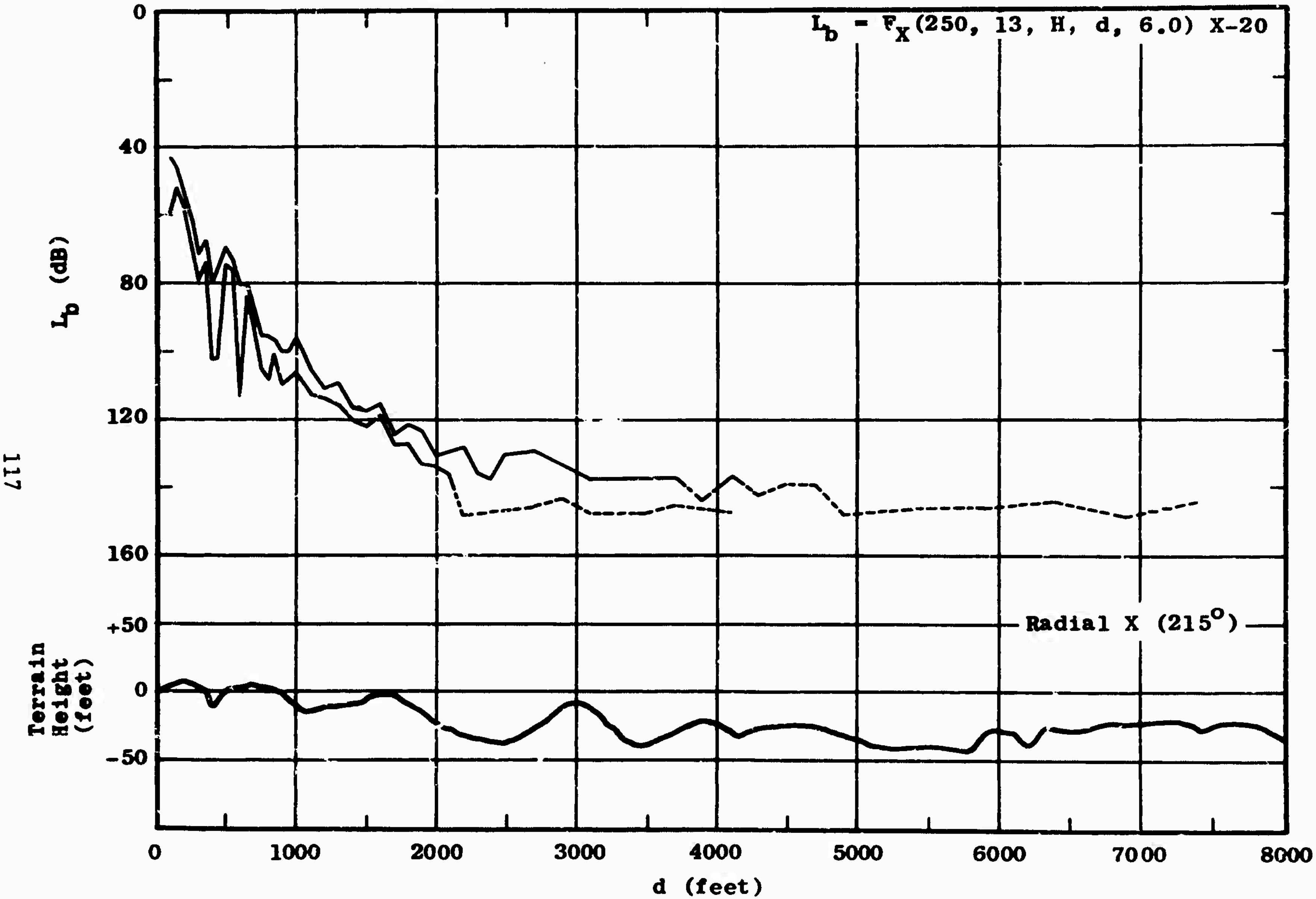

Figure 2.105 Maximum and Minimum Basic Transmission Loss as a Function of Distance

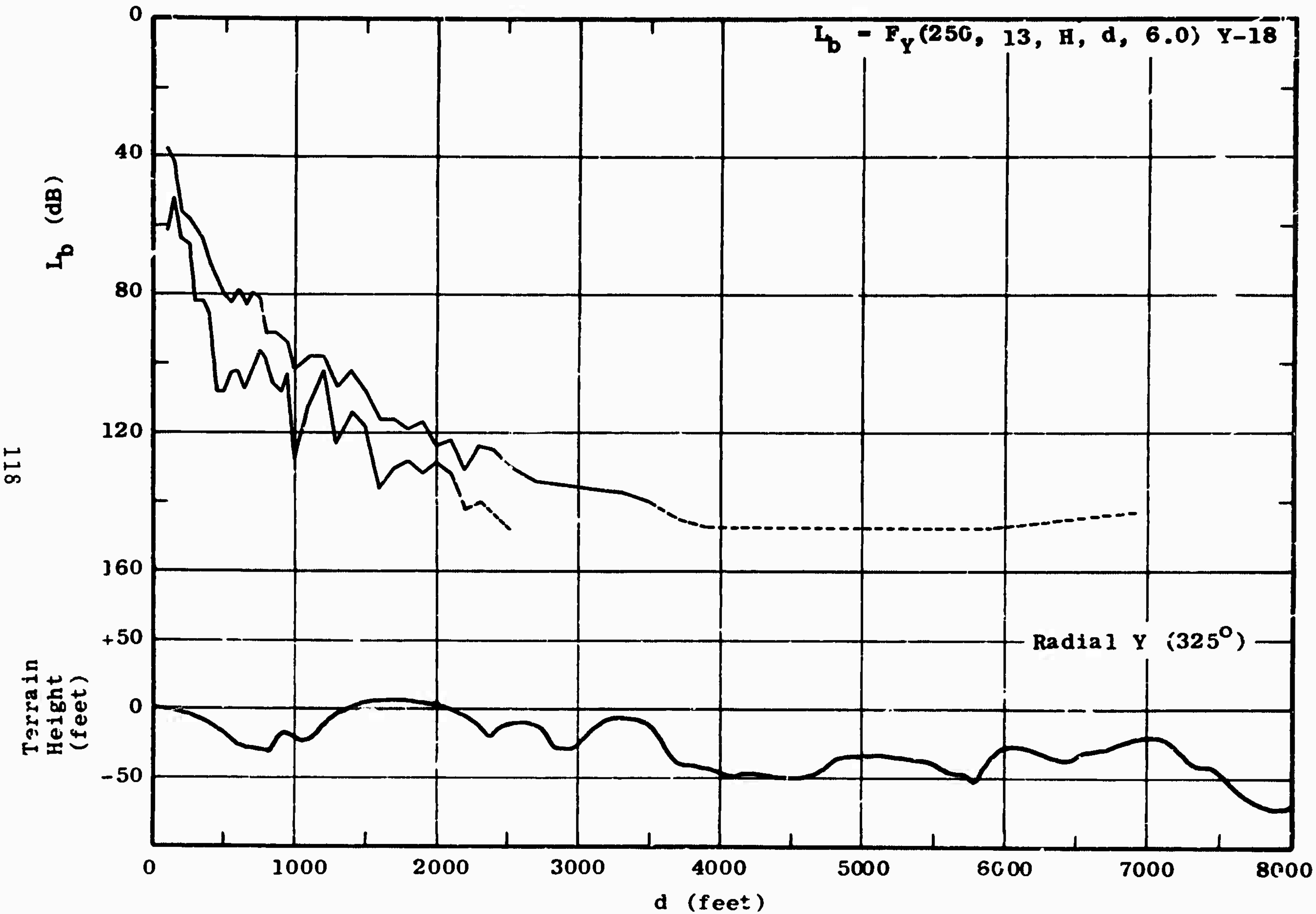

Figure 2.106 Maximum and Minimum Basic Transmission Loss as a Function of Distance

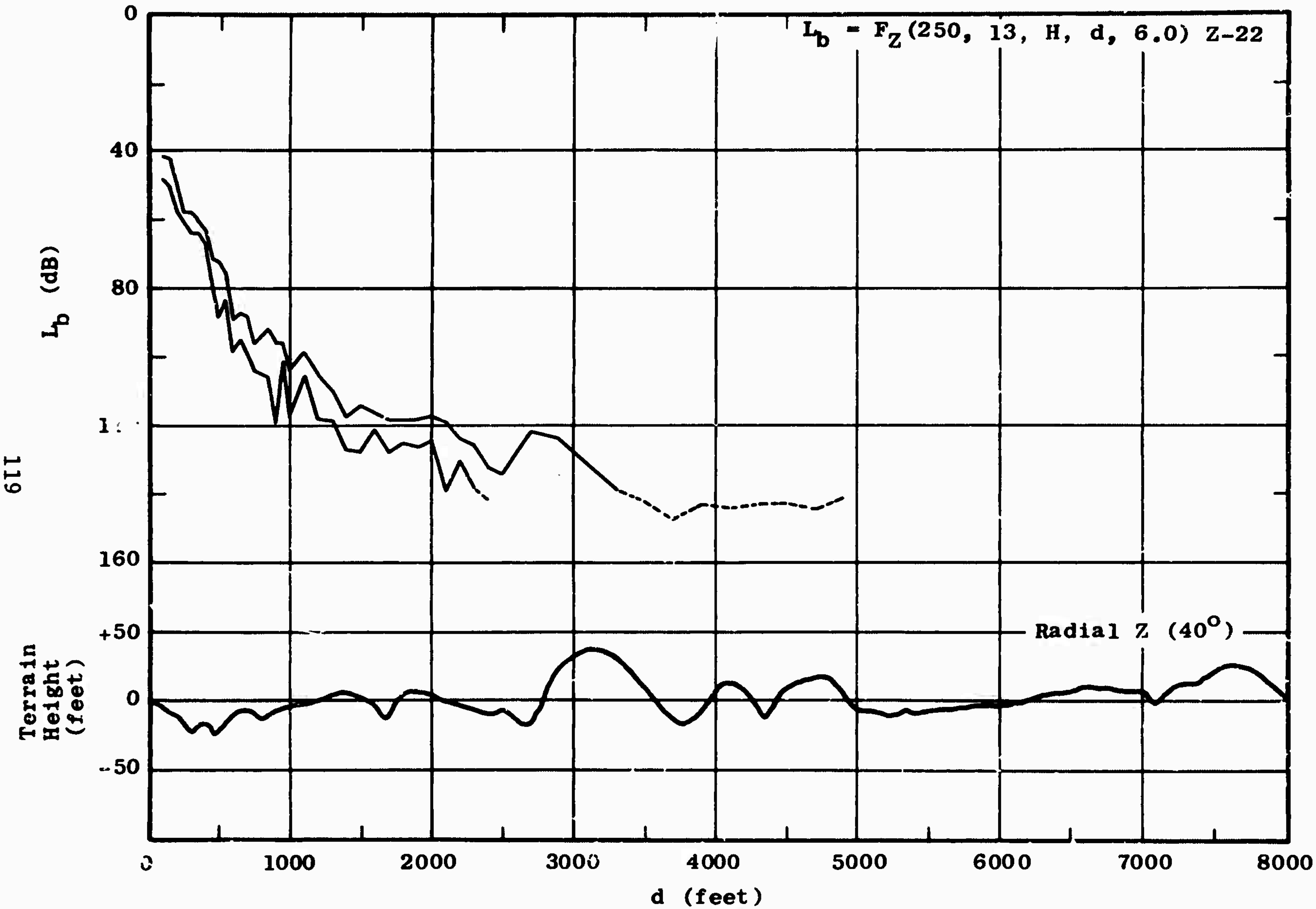

Figure 2.107 Maximum and Minimum Basic Transmission Loss as a Function of Distanc

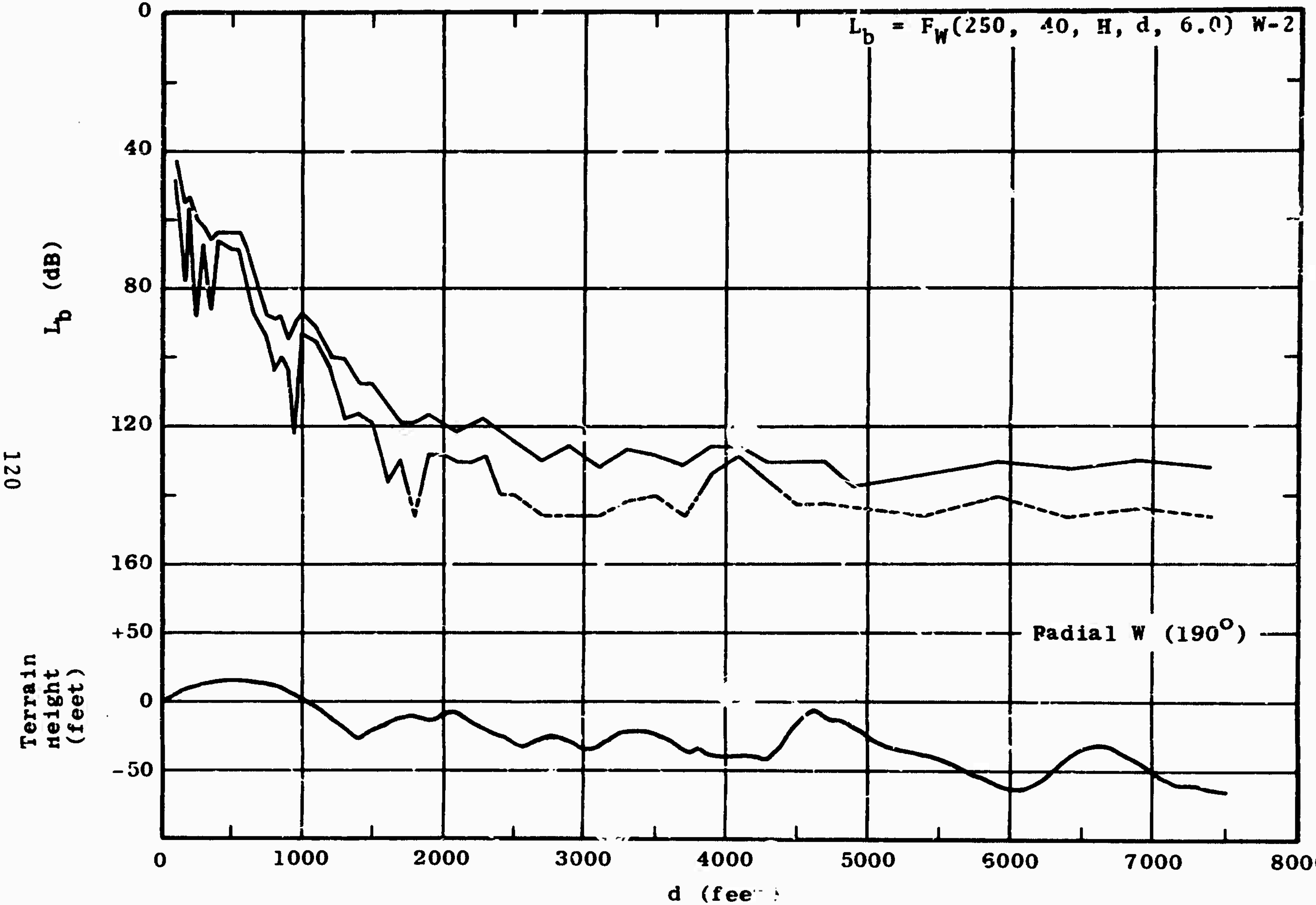

Figure 2.108 Maximum and Minimum Basic Transmission Loss as a Function of Distance

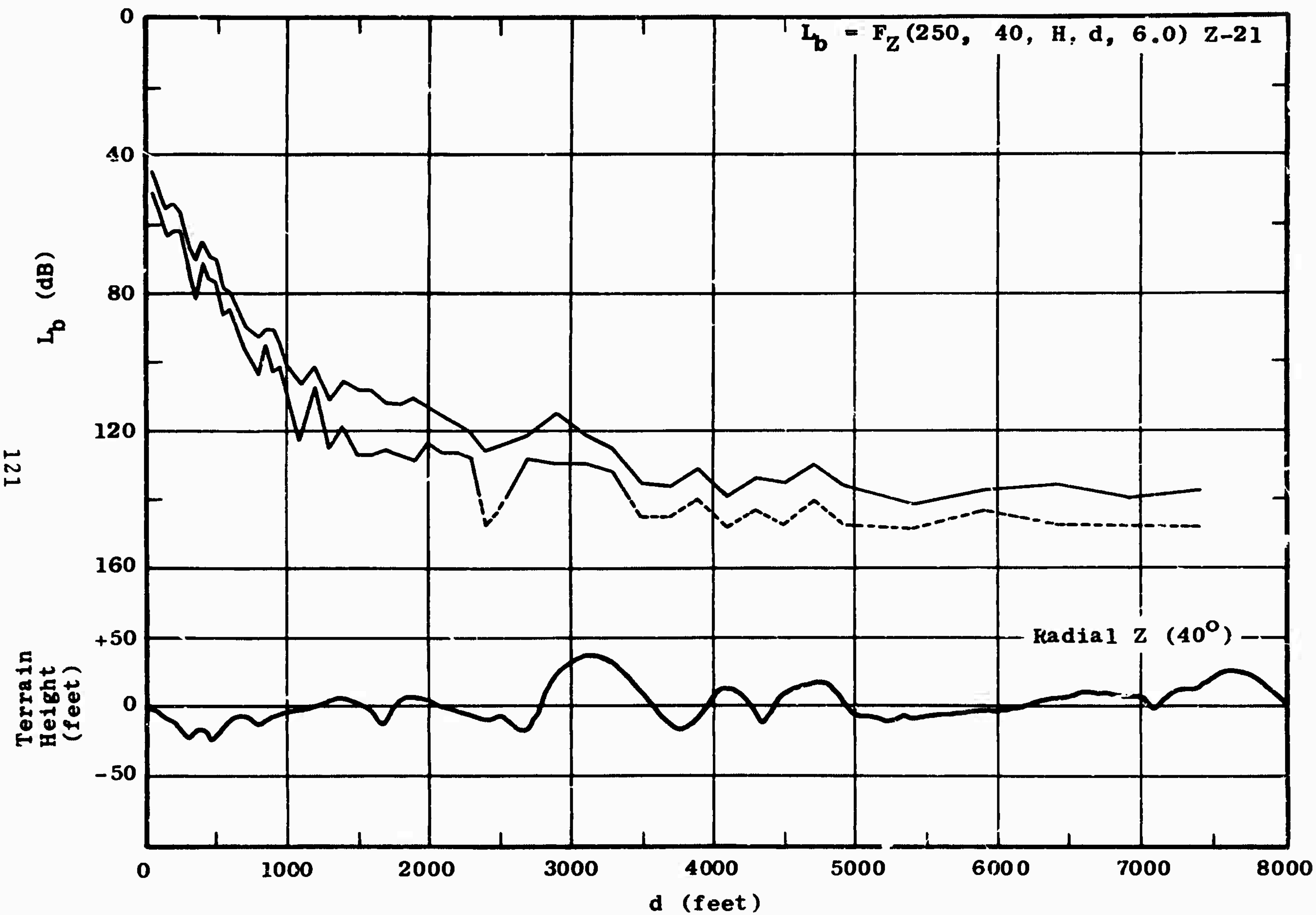

Figure 2.109 Maximum and Minimum Basic Transmission Loss as a Function of Distance

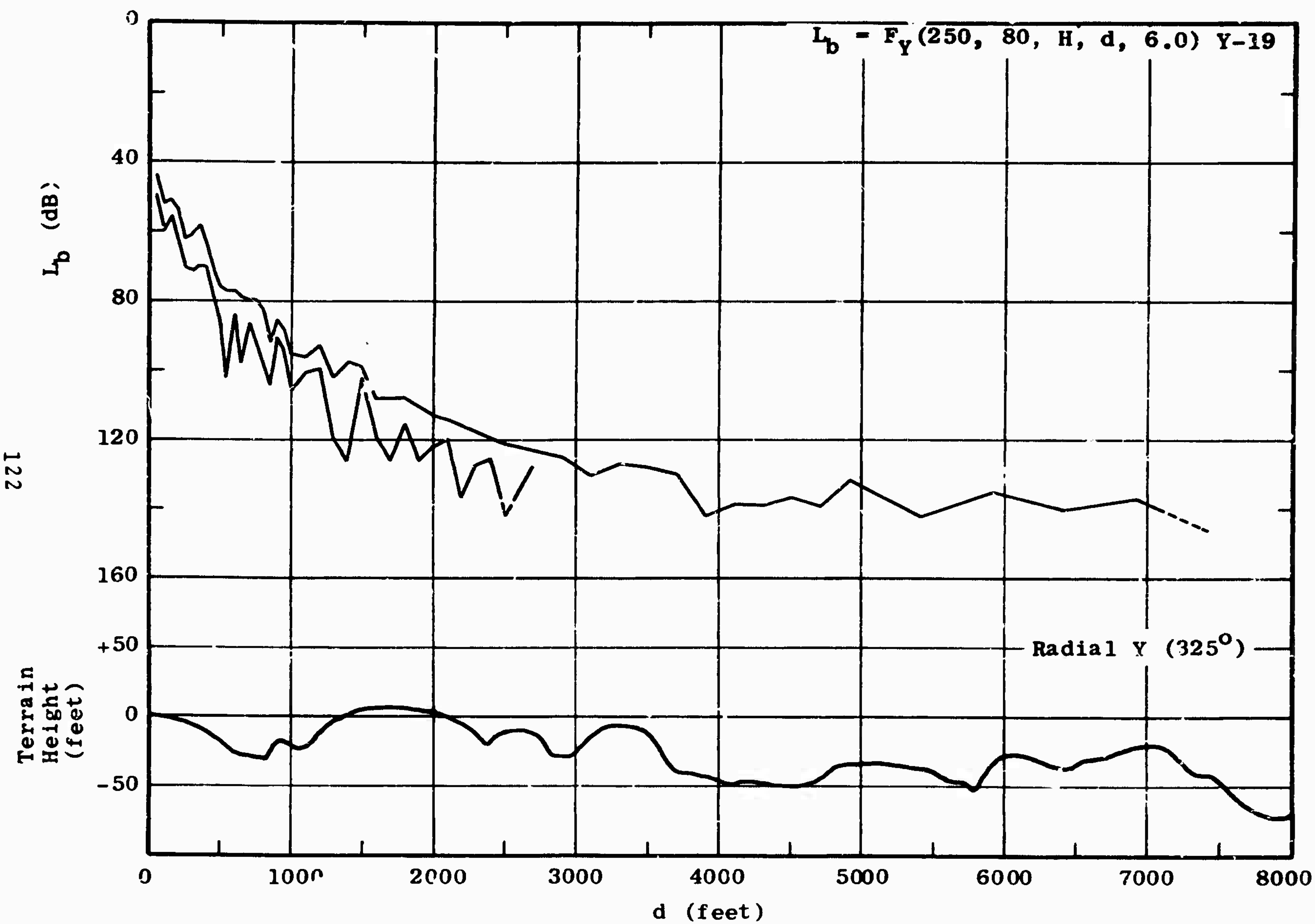

Figure 2.110 Maximum and Minimum Basic Transmission Loss as a Function of Distance

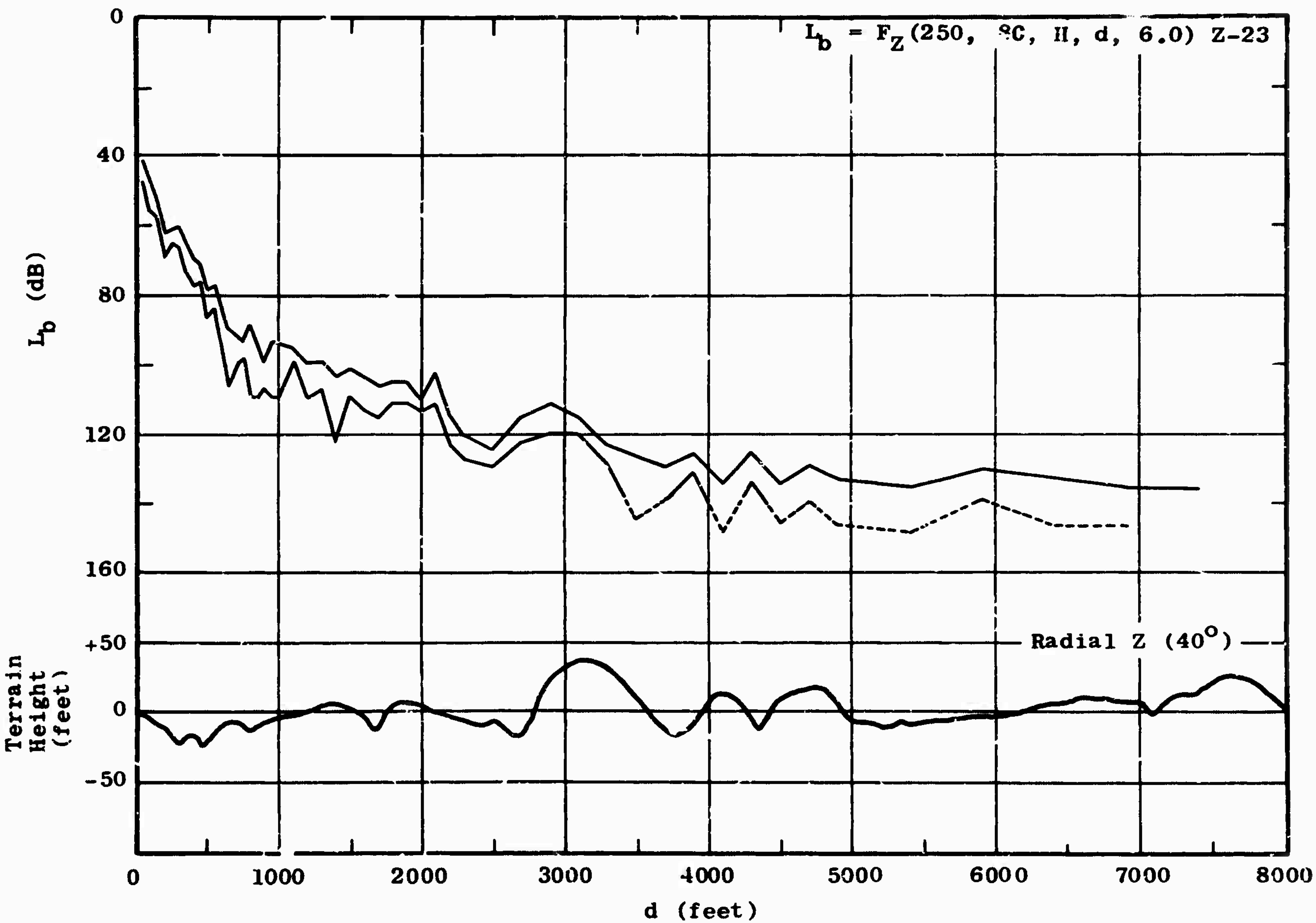

Figure 2.111 Maximum and Minimum Basic Transmission Loss as a Function of Distance

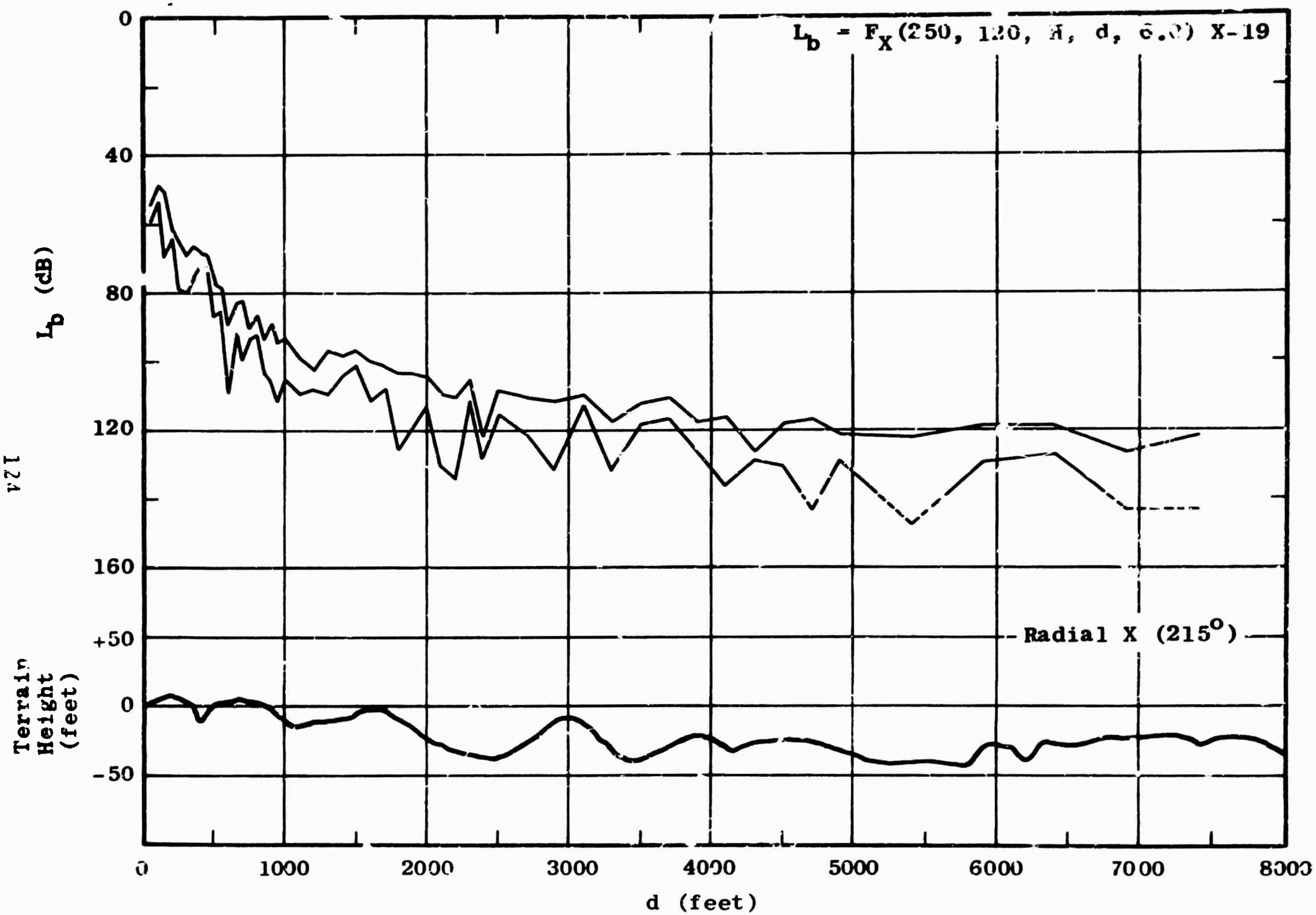

Figure 2.112 Maximum and Minimum Basic Transmission Loss as a Function of Distance

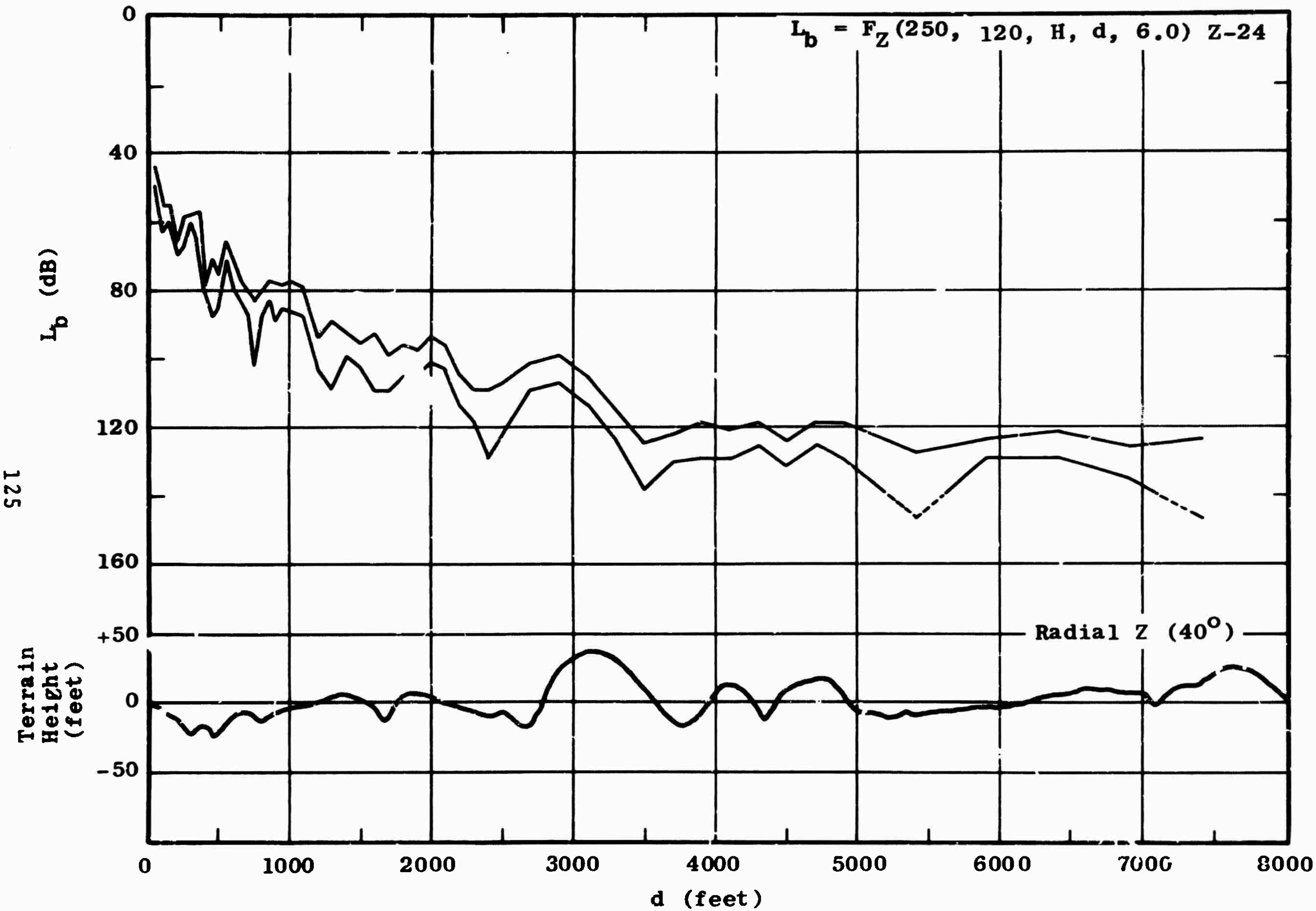

Figure 2.113 Maximum and Minimum Basic Transmission Loss as a Function of Distance

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3. COMPARISON OF WALKING DATA FROM AREA I AND AREA II

A primary goal of this research program is to determine how short-range radio propagation is affected by variations in different environmental parameters. The major parameters are terrain, weather, climate, soil, and vegetation. One criterion in selecting the Songkhla test area was that it had significantly higher and denser vegetation than existed in the Area I test area. Thus, a comparison of the Area II data with the Area I data should delineate some of the effects of varying height and density of vegetation.

The graphs in this section are drawn from short-range tests made at Area I and Area II with hand carried receiving antennas and field intensity meters. In each graph, equivalent sets of data from the two areas are superimposed on one another. The graphs contain the 13 sets of "walking" data that had identical test variables in the two areas. The test frequencies are 25, 50, 100 and 250 Mc/s. At each frequency there is at least one comparison for both horizontal and vertical polarization.

The data from each area is combined into a so-called "data envelop." There is a data envelop for each set of test parameters in each of the two areas. The envelop encompasses the highest and lowest values, i.e., the total range, of path loss recorded at the different distances from the transmitting antenna where measurements were made. Since each set of data represents readings taken over two, three or four measurement trails, the top of the envelop is

the lowest value of path loss recorded on any of the trails at that particular distance. Likewise, the bottom of the envelop is determined by the highest value of path loss recorded on any trail at that distance.

An expanded version of the identifying matrix described in Section 3.1 is used to indicate the test parameters and measurement trails for each set of data. In Figure 3.1, there are two identifying matrices:

$$\text{——}\ L_b = F_{W,X,Y,Z}(25, 13, H, d, 6)$$

$$\text{- - -}\ L_b = F_{204,234}(25, 13, H, d, 6)$$

The dashed or solid line in front of "L_b" indicates whether the matrix refers to the dashed or solid envelop. In all of the graphs, the solid lines are the data envelop from Area II, where the radials are called "W," "X," "Y" or "Z." The dashed lines come from Area I data taken on radials called "174," "204" or "234." These identifying numbers actually represent the bearing (in degrees) of each Area I radial.

The data in the parentheses of each matrix gives, respectively: transmitting frequency (in Mc/s), transmitting antenna height (in feet), polarization, path length and receiving antenna height (in feet). Thus, Figure 3.1 combines data from radials W, X, Y and Z at Area II, and from radials 204 and 234 at Area I for 25 Mc/s, using horizontal polarization with a transmitting height of 13 feet and a receiving height of 6 feet.

From a standpoint of drawing conclusions, the data contained in this preliminary comparison is too limited to warrant any major statements about differences between Area I and Area II. In only five instances was the Area I data recorded at distances greater than 1000 feet, and in two of the cases at 25 Mc/s, using horizontal polarization, there were not enough readings to construct more than a single dotted line beyond 1000 feet. Only a few tentative observations can be made until the results of height-gain comparisons between Area I and Area II are correlated with these walking data comparisons.

These observations are based only on the data that is available for distances beyond 1000 feet. For shorter distances the mode structure is extremely complicated since direct waves, as well as ground reflected waves contribute to the electromagnetic field making meaningful comparison between different areas very difficult.

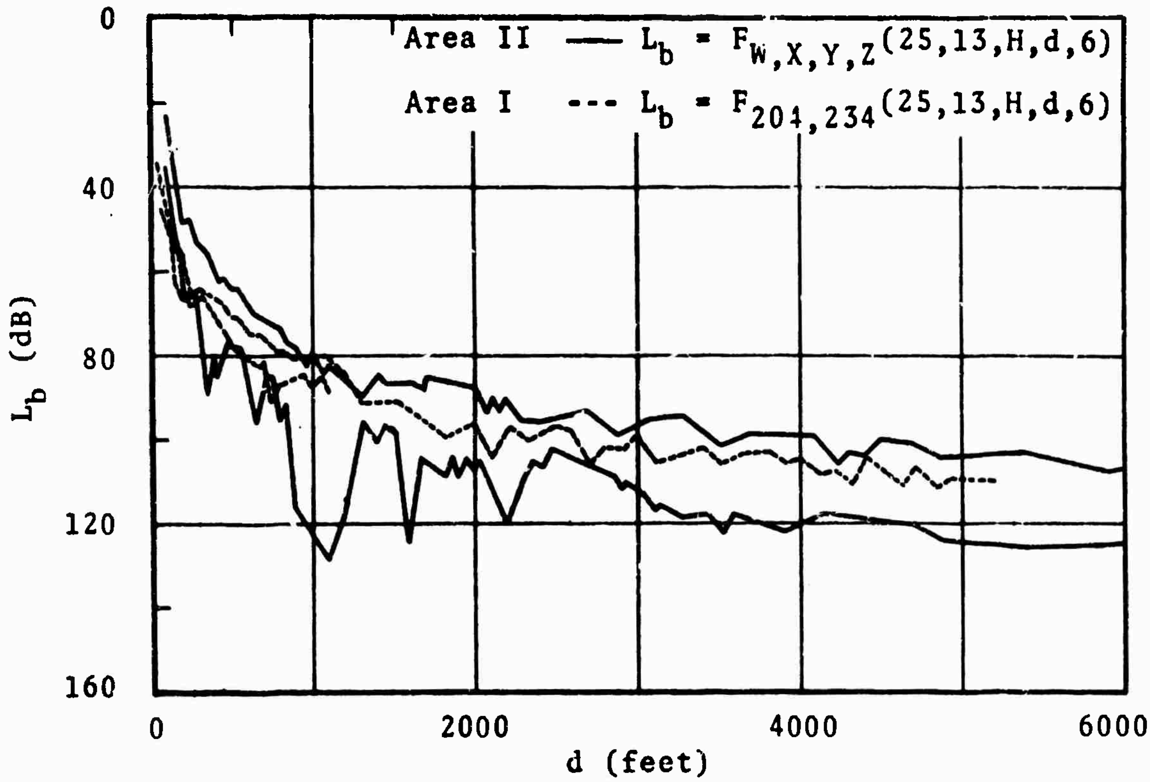
Based on the three Area I data envelopes at 50 Mc/s that extend to one mile, it can be said that basic path loss is greater at Area II where the vegetation is denser and taller than at Area I. The data, and the two sets of single lines at 25 Mc/s, also show that the difference between the loss at Area I and Area II is fairly independent of distance for distances greater than about 2000 feet. That the difference in basic path loss between the two areas is independent of distance beyond this nominal distance is not surprising. It supports the theory that the principal mode of propagation in a vegetated area is along the treetop boundary, (i.e., the lateral wave[1]). According to this theory the vegetation introduces losses only along the portion of the total path from the transmitter to the

treetops and from the treetops to the receiver. Since the trees are taller at Area II, these paths, for a given antenna height above ground, are longer and hence result in greater loss.

This, of course, does not mean that the energy propagates along treetops without loss. There is in the case of the lateral wave a loss which represents energy leaking back into the jungle as it propagates along the treetops. This loss will be a function of the effective conductivity of the jungle, but for these distances a solution for the lateral wave shows that to a first order approximation the loss depends on distance as 40 log D (distance) and is independent of jungle conductivity.

Differences in conductivity will cause path loss to the treetops to differ in the two locations. However, much more analysis of the data will be needed to determine the effects of any differences in conductivity in the two areas. Since the jungle is more dense at Area II, the effective conductivity should be greater there. As a result, at shorter distances where the "through-the-foliage" mode is significant, we would expect greater losses in Area II. This is not always the case, however, as the graphs show.

The problem of assessing the effects of conductivity is further complicated by the non-homogeneous vertical characteristic of the vegetation. In Area I, trees are shorter but some of the low undergrowth is quite dense. In Area II, the trees are much taller and there exists a dense canopy. As a result, the low undergrowth is not as dense.



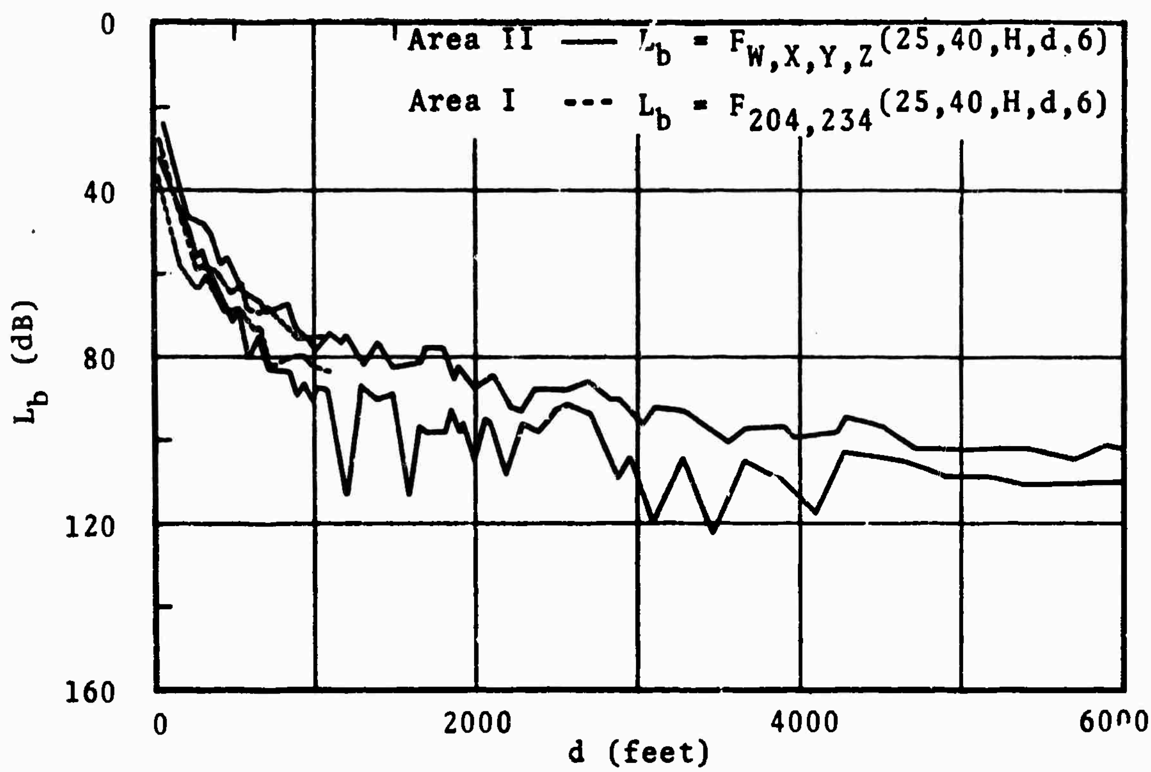


Figure 3.1 Basic Transmission Loss at Area I and Area II

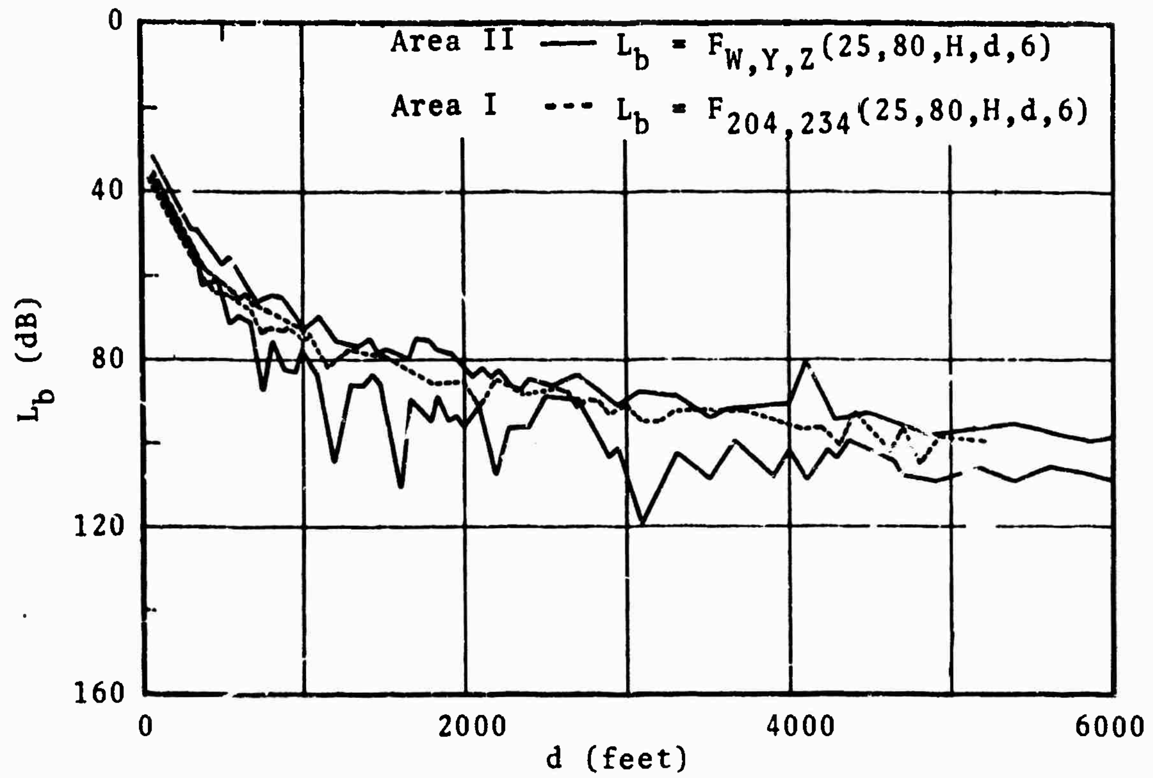


Figure 3.2 Basic Transmission Loss at Area I and Area II

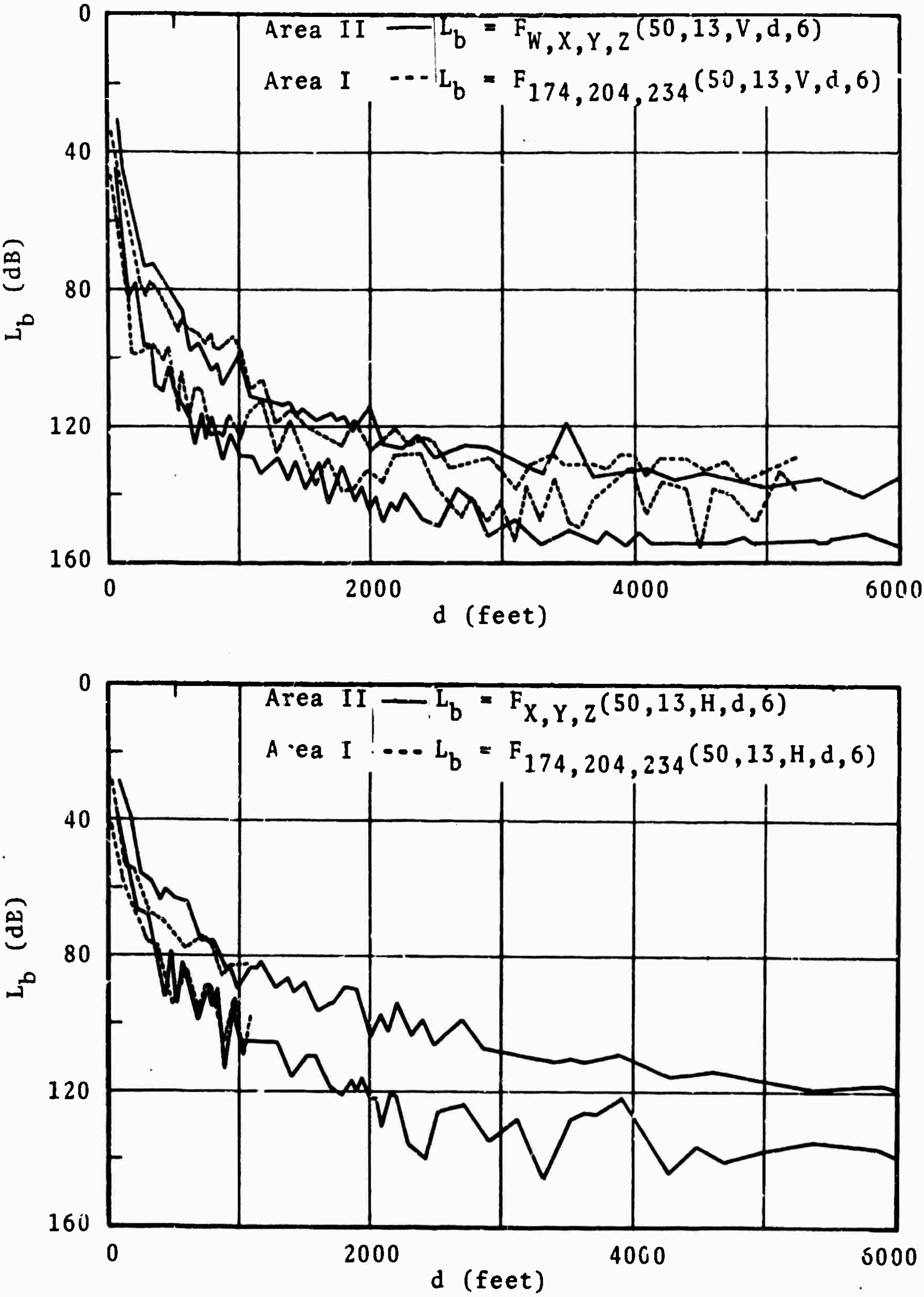
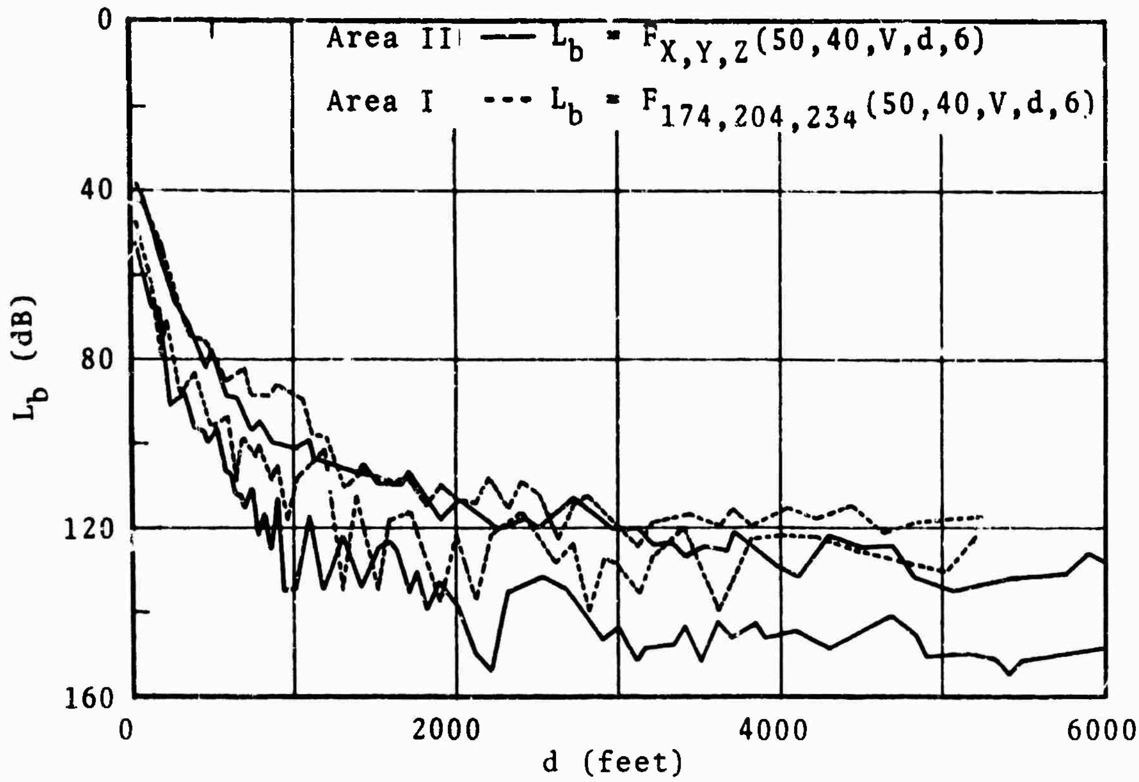


Figure 3.3 Basic Transmission Loss at Area I and Area II



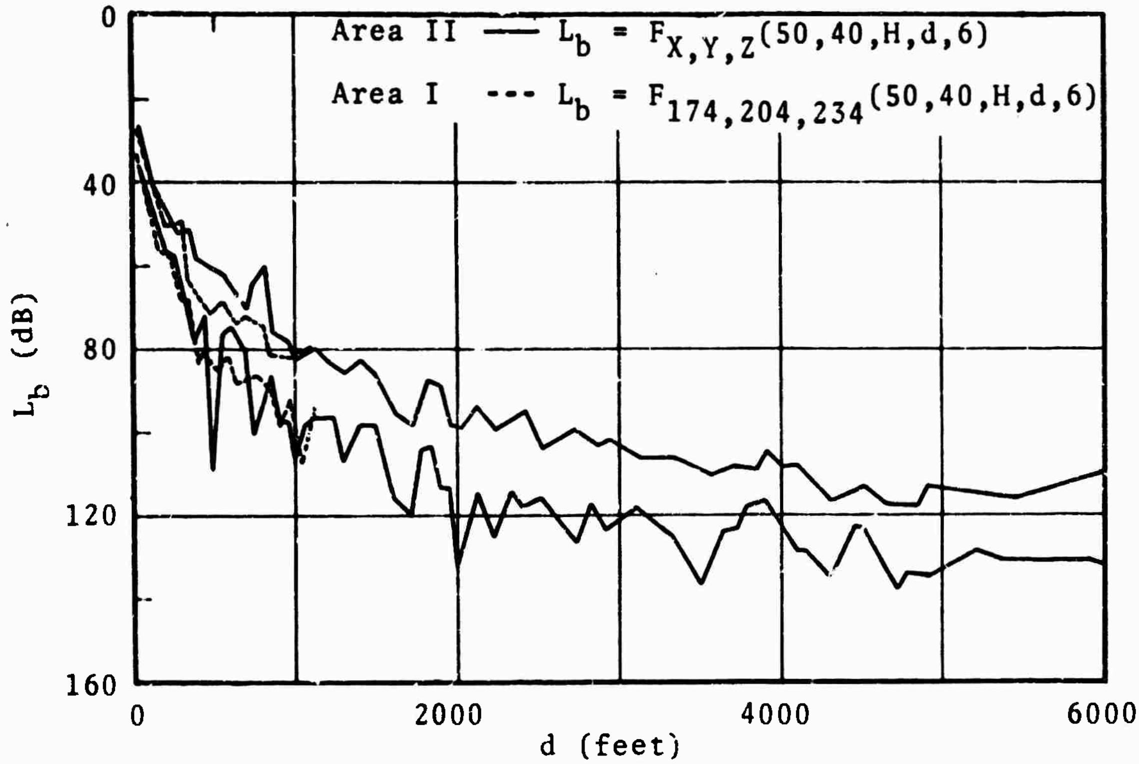


Figure 3.4 Basic Transmission Loss at Area I and A~ea II

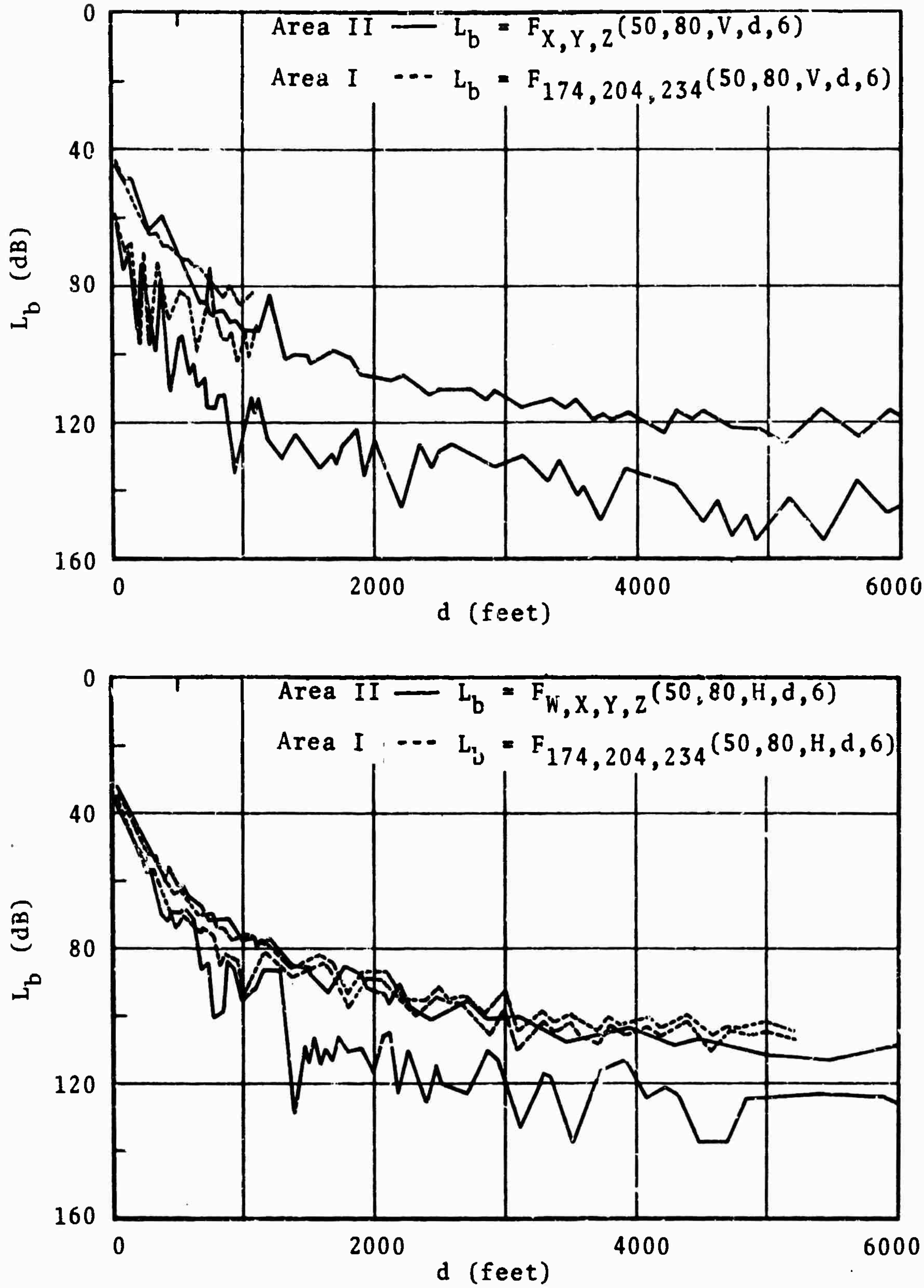


Figure 3.5 Basic Transmission Loss at Area I and Area II

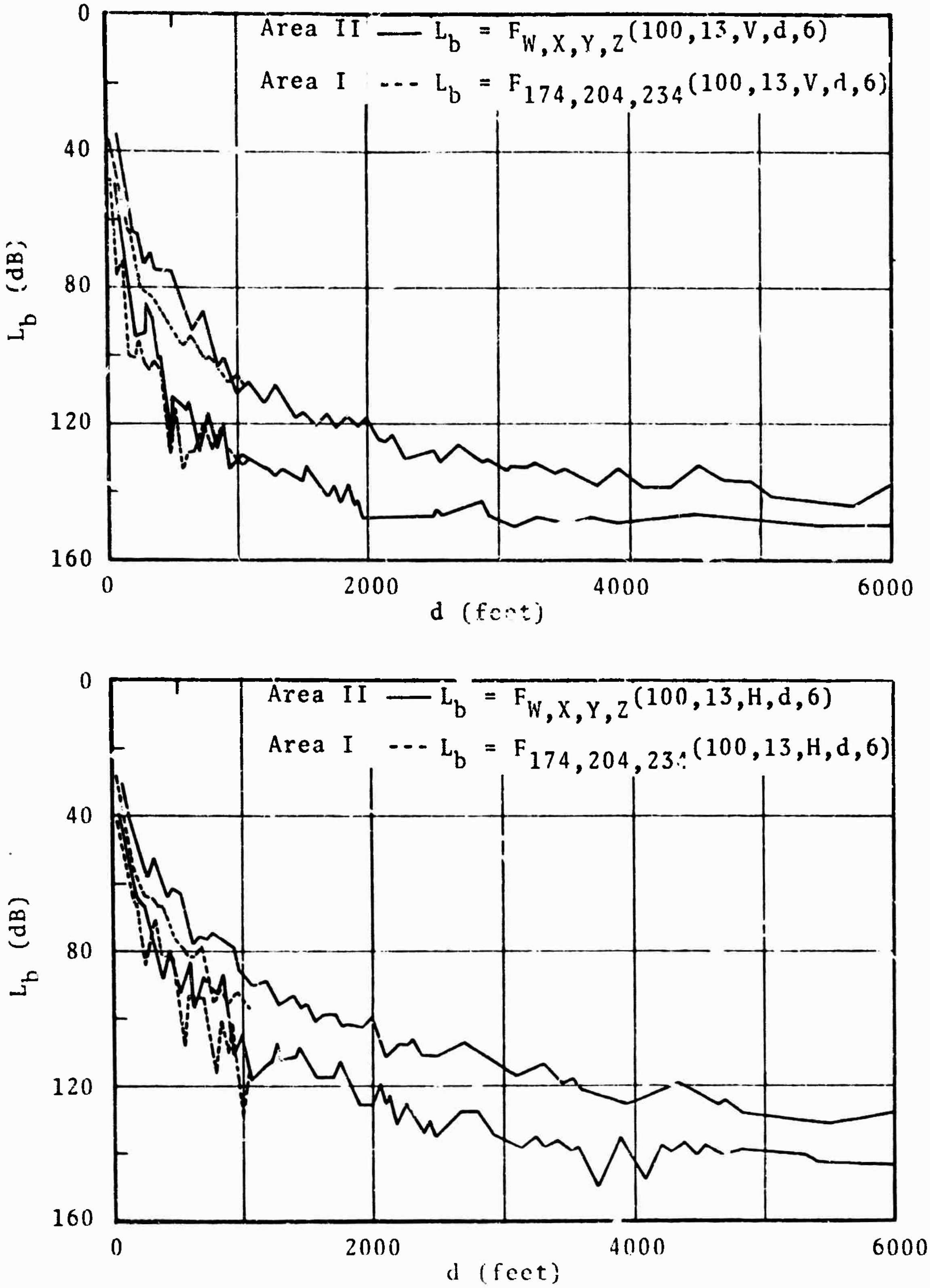


Figure 3.6 Basic Transmission Loss at Area I and Area II

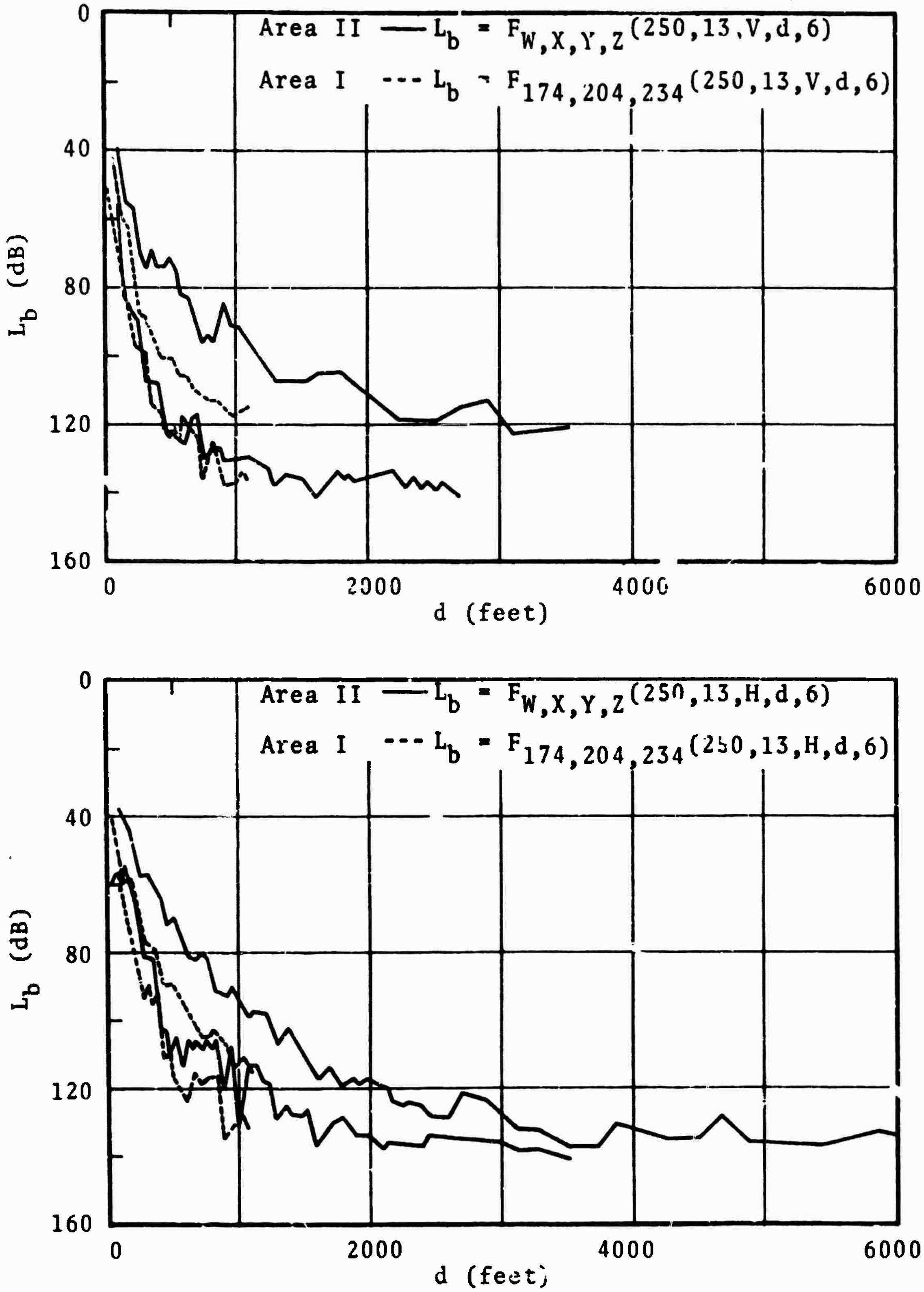


Figure 3.7 Basic Transmission Loss at Area I and Area II

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4. CLIMATOLOGICAL DATA

Since November 1966, various climatological parameters have been measured in the Area II test area. The instruments for taking this data are situated within the base site. In general, the data consists of maximum and minimum daily temperatures, the results of hygrometer readings taken in the morning, at noon, and in the afternoon, and a continuous record of rainfall. The rain gauge is an automatic instrument which can run one week without attendance. All other readings are daily samplings.

Since helicopter transportation to the test site was only scheduled for five days a week, these readings could not be made every day. Over the seven-month period covered by the data presented here, daily readings were taken 66 per cent of the time. This rate of sampling is frequent enough to give an accurate picture of the trends in average monthly temperature and humidity.

Figure 4.1 is based on readings from the maximum and minimum temperature indicator. This instrument will record and retain the highest and lowest temperatures over any period until it is reset. Thus, this data would reflect temperature extremes that occurred on days when no readings were taken, since their values would be retained when the instrument was later read. The curve in Figure 4.1 is the average monthly temperature, and the bars bracketing each monthly period represent the highest and lowest temperatures recorded by the instrument during the month. The average temperature is derived by calculating a daily temperature halfway between the maximum and minimum

of each day and by averaging all these middle temperatures for a particular month. The figure indicates that the lowest temperatures at the test area for the first half of the year are around 70 degrees Fahrenheit. Between December and June the maximum temperatures climb from about 90 degrees Fahrenheit to 120 degrees Fahrenheit, and the average temperature increases from 80 degrees Fahrenheit to 90 degrees Fahrenheit.

The morning humidity tests were made before 10 AM, the noon tests between 10 AM and 2 PM, and the afternoon tests after 2 PM. To reduce the data, all the readings made before 10 AM were averaged. This procedure was repeated for the noon and afternoon readings, and then the three averages were themselves averaged to obtain a representative reading of the monthly humidity. These values of monthly humidity are plotted in Figure 4.2. Also shown in Figure 4.2 are the highest and lowest humidities recorded on all the tests during each month. From this data it appears that the maximum relative humidity is essentially never higher than 90 per cent, and that the average humidity varies from 80 per cent during periods of heavy rainfall to 65 per cent during relatively dry periods.

Figure 4.3 illustrates the differences and similarities between the climates at Area I and Area II. The two sets of curves in this figure represent the monthly humidity, temperature and rainfall recorded at the two test sites during the same part of a year.

The rainfall data is taken from a continuously operating rainfall recorder which was stationed at the base

sites of both test areas. The data for the temperature and humidity curves comes from the morning, noon and afternoon hygrometer tests made at both sites. The monthly values of rainfall and humidity are obtained by the same technique described in conjunction with Figure 4.2. Thus, the Area II humidity curve in Figure 4.3 is the same curve shown in Figure 4.2. It should be noted, however, that the Area II temperature curve in Figure 4.3 is not exactly the same as the temperature curve in Figure 4.1, which is based on the maximum and minimum temperatures of the day rather than on the dry bulb temperature recorded during the daytime humidity tests. The result of using the maximum and minimum daily temperature instead of a sampling of daytime temperatures is that the curve in Figure 4.1 indicates average monthly temperatures which, from December to April, are about 4 degrees Fahrenheit lower than the averages indicated by the Area II curve in Figure 4.3. This difference is due to the low nighttime temperature during that period which slightly lowered the values of the average monthly temperatures shown in Figure 4.1.

Based on the data shown in Figure 4.3, Area I received about 22 inches of rainfall from November to June, whereas Area II received about 40 inches. Temperatures for the two areas are nearly the same. The humidity at Area II while noticeably higher than at Area I, is not significantly so. Thus, the outstanding climatological difference between the two areas is rainfall, which is about two times heavier at Area II.

Since the Area I climatological information in Figure 4.3 is based on averages of data recorded in 1964, 1965 and 1966, it can be assumed that the values are fairly

representative of normal conditions. The Area II rainfall, which was recorded over a single period and which constitutes the greatest difference between it and the Area I site, has been checked with average records of rainfall for the general Songkhla region based on 30 years of data accumulated by the Thai Meteorological Department. Figure 4.4 compares rainfall accumulation recorded at the Area II test site from mid-November to mid-June with average rainfall for the region. It can be seen that the two records of rainfall diverge somewhat during December. This behavior is due to unusually heavy rain in that month which flooded the country-side for a period of time and forced the field crew to relinquish the helicopter so that it could be used for rescue work. During February and March of 1967 the rainfall was unusually low, and in that period the rain accumulation again approached the average. Thus, the accumulated Area II rainfall indicated in Figure 4.3 does not deviate significantly from the average accumulation.

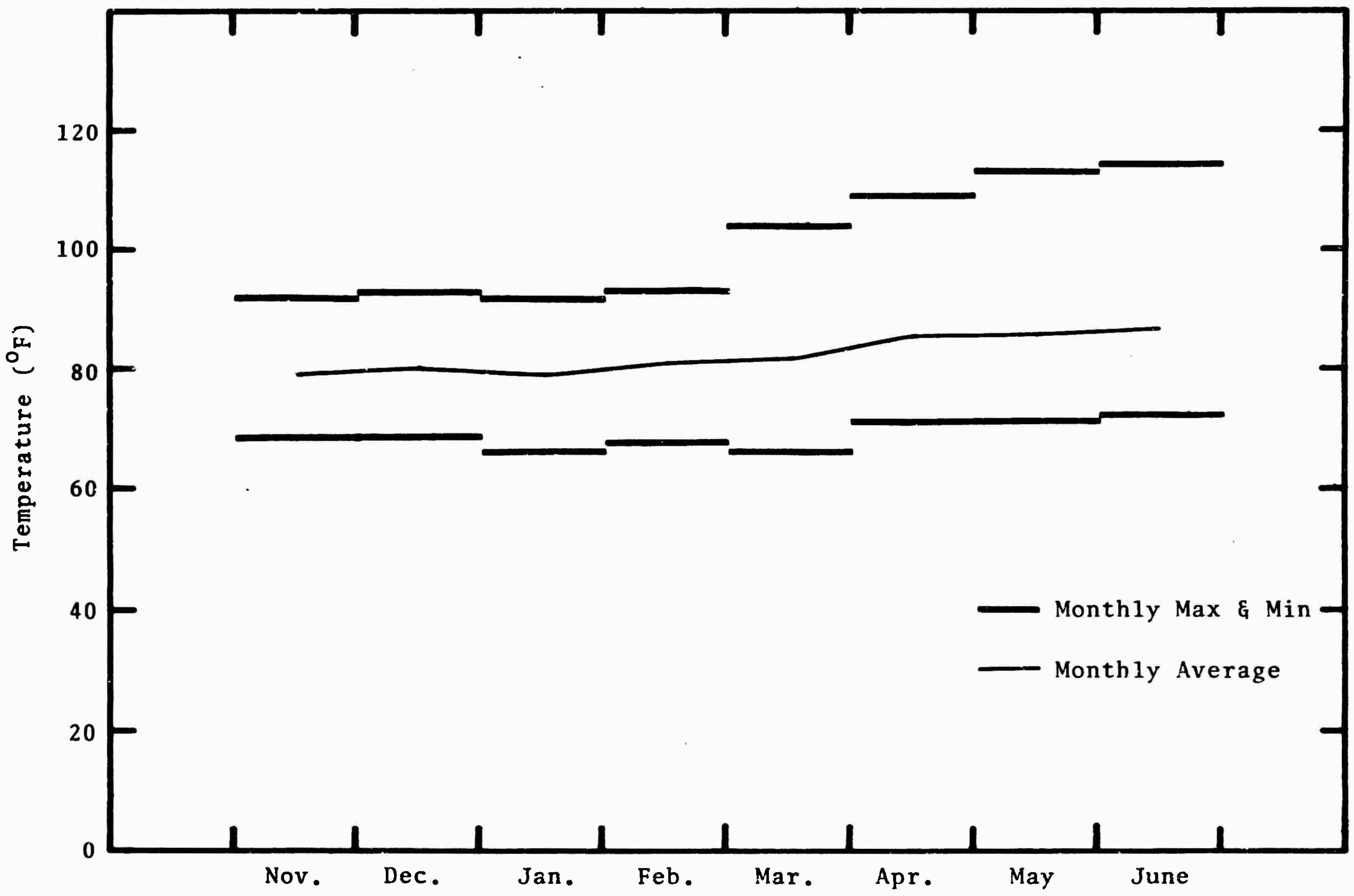

Figure 4.1 Average and Extreme Temperatures at Area II Test Site

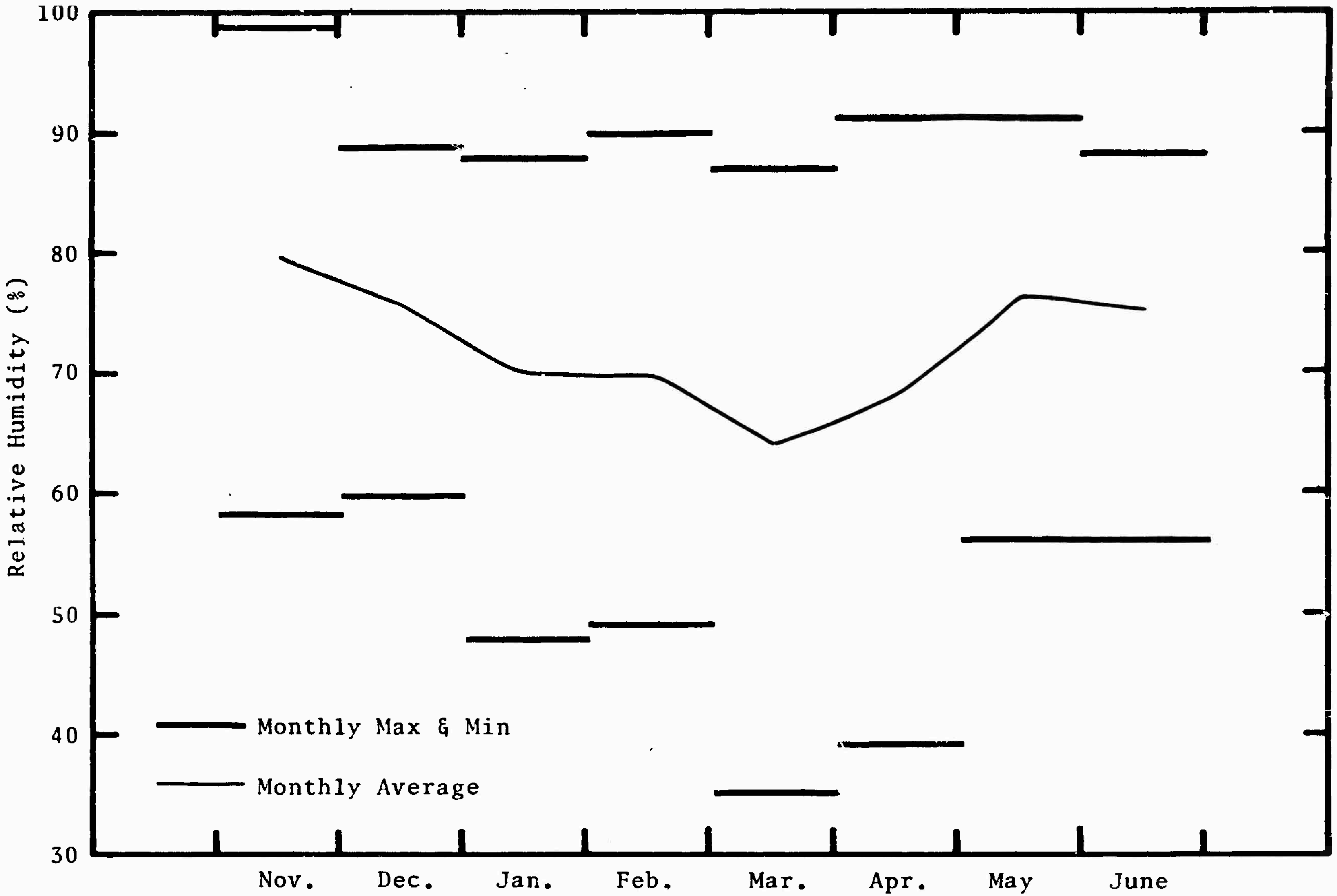

Figure 4.2 Average and Extreme Humidities at Area II Test Site

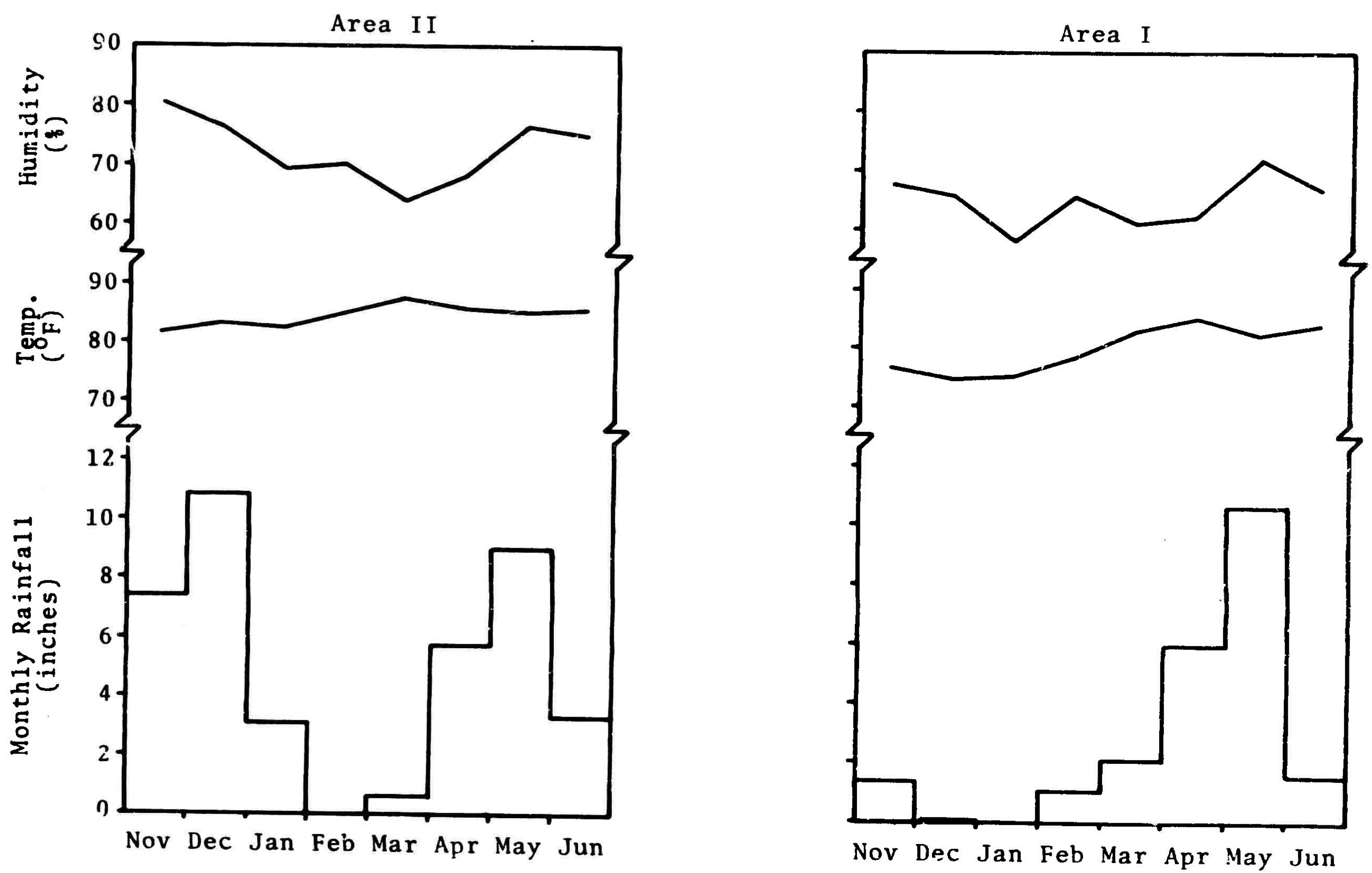

Figure 4.3 Comparison of Area II and Area I Climatological Data

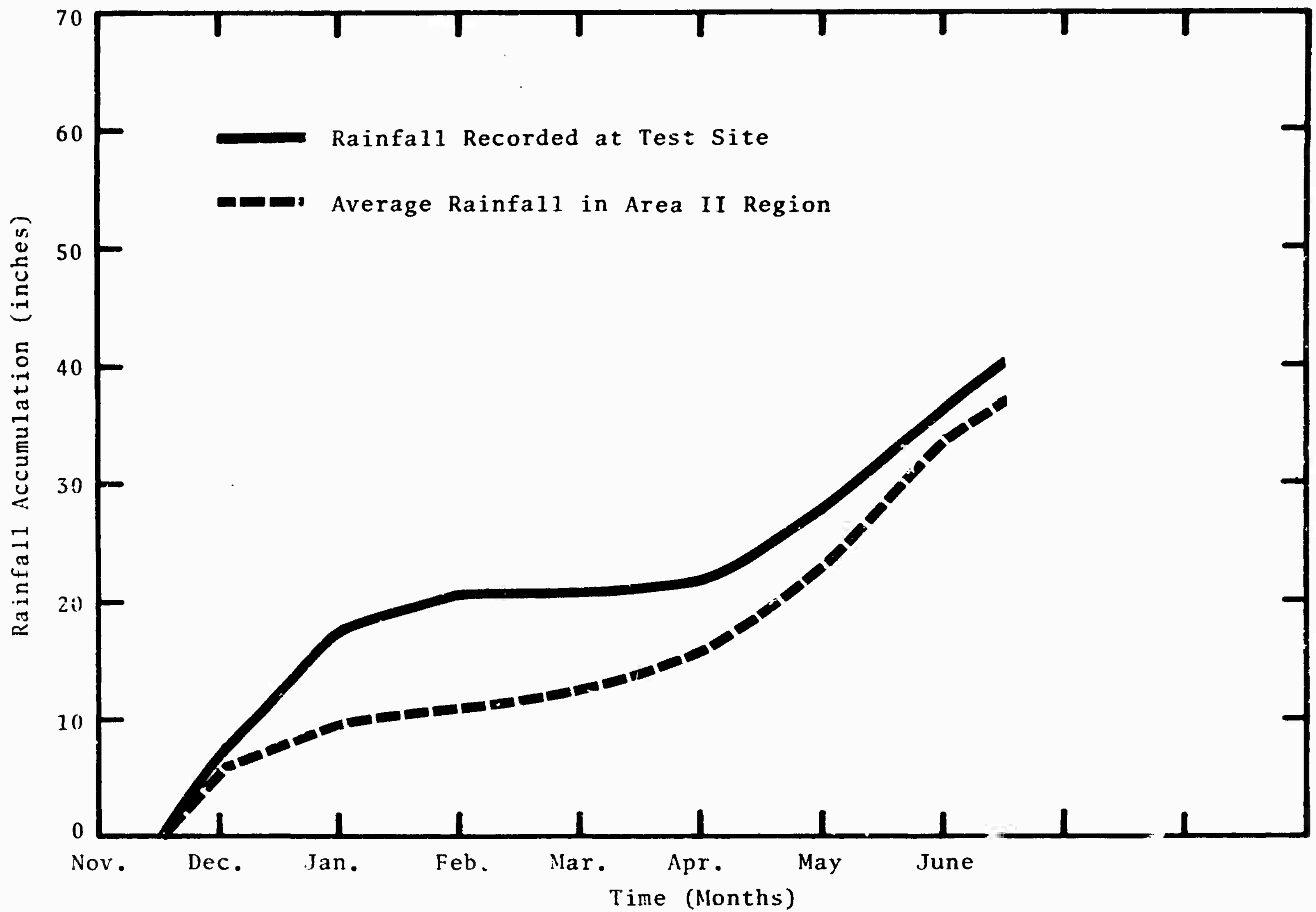

Figure 4.4 Average and Recorded Rainfall Accumulation

5. LIST OF PERSONNEL

The following individuals have made significant contributions to the work accomplished during this report period.

Sturgill, Lester G. - Manager, Antennas and Propagation Group, and Project Director

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Schairer, Neil J. - Project Engineer, Instrumentation

Sykes, Charles B. - Project Engineer, Field

Redden, Donald R. - Field Administrator

Anti, Per A. - Field Engineer

Ayers, Robert W. - Field Technician

Backus, William A. - Propagation Analysis Engineer

Banning, Craig M. - Data Technician

Barton, Richard - Propagation Analysis Engineer

Bass, Robert F. - Field Engineer

Conway, Charles O. - Field Technician

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Cross, Gerald E. - Field Technician

deLacy-Bourke, Jocelyn - Technical Editor

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Grant, Jesse J., IV - Field Engineer

Heisler, Kenneth G., Jr. - Propagation Analysis Engineer

Kocherhans, Christhelm R. - Field Technician

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Lucha, Gerald V. - Field Engineer
Murphy, A. Page - Propagation Analysis Engineer
Munson, William B. - Propagation Analysis Engineer
Patrick, Eugene L. - Propagation Analysis Engineer
Purves, Lloyd R. - Assistant to Project Director
Ragan, S. Morgan - Field Engineer
Robertson, Richard G. - Field Engineer
Seneker, William P. - Propagation Analysis Engineer
Them, Albert H., III - Propagation Analysis Engineer
Townsend, I. Ann - Data Technician

REFERENCE

1. L. L. Sachs and P. J. Wyatt, A Conducting Slab Model for Electromagnetic Propagation Within a Jungle Medium, Defense Research Corporation, DA-31-124-ARO-D-312; May 1966, (Unclassified).

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13. ABSTRACT

This is the ninth semiannual report of a research project to study radio propagation in tropical areas with heavy vegetation. The experimental results reported here are from the first series of tests conducted near the towns of Songkhla and Satun in southern Thailand (Area II). The test area, which receives about 90 inches of rainfally annually, is covered with extremely thick jungle. Graphs are presented of basic transmission loss as a function of distance out to 1.4 miles for frequencies of 25, 50, 100 and 250 Mc/s using different transmitting antenna heights, polarizations and transmission paths. The receiving antenna height is fixed at 6 feet. Certain of these tests are compared with identical ones made previously in the jungles near Pak Chong, Thailand, (Area I), where the vegetation is significantly lower and less dense. The climate in the test area is also described and compared with the climate at Area I.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Propagation						
Techniques						
Tropical Environment						
SEA - Southeast Asia						
Thailand - SEA						
Path Loss						
Climatology - Rainfall, Temperature, Barometric Pressure						
Antenna Height						
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